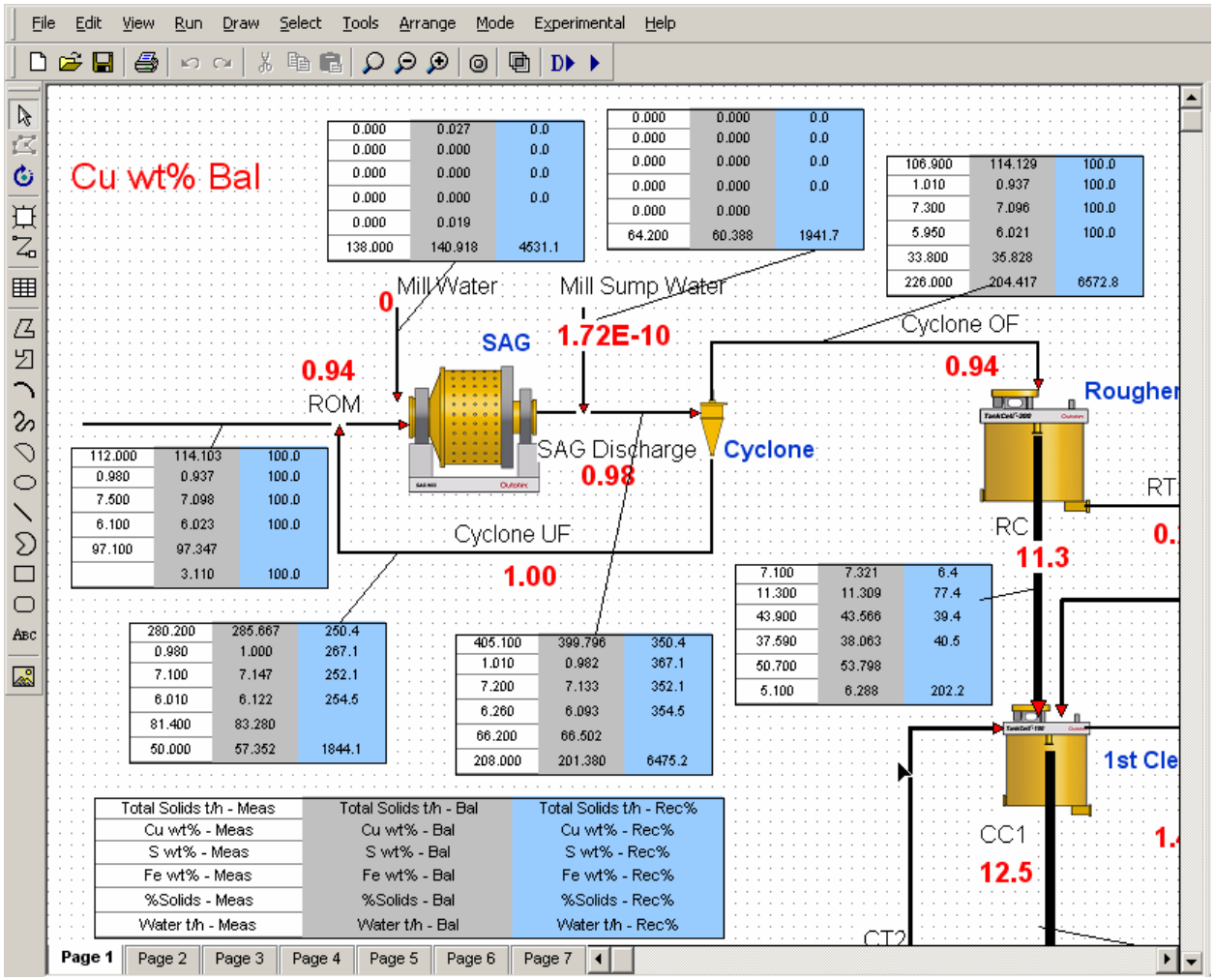
HSC Chemistry® 7.0 User's Guide

Mass Balancing and Data Reconciliation

Pertti Lamberg and Jaana Tommiska



Outotec Research Oy
Information Service
P.O. Box 69
FIN - 28101 PORI, FINLAND
Fax: +358 - 20 - 529 - 3203
Tel: +358 - 20 - 529 - 211
E-mail: hsc@outotec.com
www.outotec.com/hsc

48. MASS BALANCING AND DATA RECONCILIATION

48.1. General

Mass balancing is a common practice in metallurgy. The mass balance of a circuit is needed for several reasons:

- To estimate the metallurgical performance of the circuit
- To locate process bottlenecks and for circuit diagnosis
- To create models of the processing stages
- To simulate the process.

The following steps are often required to simulate a process:

1. Collecting experimental data (experimental work, sampling, sample preparation, assaying)
2. Mass balancing and data reconciliation of the experimental data
3. Model building
4. Simulation

Currently in HSC you can do all the steps in one program: HSC Sim. To work with experimental data, please see manual “47 HSC Experimental.doc”, for model building, see “79 Sim Data Fit.doc” and for simulations, see “40 Sim Flowsheet.doc”, “41 Sim Reactions Example.doc”, “43 Sim Distribution Sample.doc”, “44 Sim Distribution Examples.doc”, “45 Sim Particles.doc” and “46 Sim Particles Examples.doc”.

HSC7 allows the user to solve the following mass balance problems (Table 1):

1. Reconcile measured or estimated component flowrates (1D components).

- The component flowrate has been measured or estimated in some of the process streams. Optionally user can give an estimate of the component between the output streams of each unit for the streams where there is no flowrate value. The component can be, for example, total solids flowrate, water flowrate, copper flowrate etc.
- HSC solves the flowrate of each component (and distribution between the output streams of each unit) independently.

2. Mass balance and reconcile chemical analyses (1D assays)

- The chemical composition of each stream has been analyzed but the flowrates have not been analyzed, the flowrate of one feed stream has to be given (e.g. 100)
- HSC solves the flowrates and reconciles analyses

3. Mass balance minerals in minerals processing circuit (1D Minerals)

- The chemical composition of each stream has been analyzed and mineralogy is known; i.e. the minerals present and their chemical composition are known.
- HSC converts the elemental grades into mineral grades, solves total solids flowrates, reconciles mineral grades (with condition that their sum = 100%), and converts the mineral grades into balanced elemental grades.

4. Mass balance size distribution and water balance (1.5D)

- Size distribution of streams has been analyzed as well as %solids; flowrates of some of the streams are known
- HSC mass balances

5. Mass balance assays and components in 2- or 3-phase systems where the bulk composition is not analyzed (2D Components)

- The component concentrations have been analyzed in different substreams (solids, liquid, gas) but the composition of bulk stream is not known. The flowrates of different substreams have been measured. In some of the units, the components may change the substream (e.g. in leaching, copper is transformed from a solid to liquid)
- HSC solves flowrates and analyses of each substream.

6. Mass balance minerals or chemical assays size-by-size (2D Assays)

- Chemical composition of the solids has been analyzed, they have been sized (separated in size fractions) and mass proportion and chemical composition of the size fractions has been analyzed.
- If desired, HSC converts elemental assays to mineral grades, solves first 1D mass balance and uses the 1D mass balance to

7. Mass balance particles, MLA assays (3D)

- Particle composition of the streams has been analyzed by size fractions; in addition frequently chemical assays has been done on unsize and size-by-size basis; mass proportion of each size fraction has been measured
- HSC solves first 1D mass balance, then 2D mass balance using the 1D solution as constraints. HSC classifies particles and mass balances particle classes in a way that the balance is in harmony with 1D and 2D balances.

*Table 1. Mass balance cases that can be solved with HSC Sim. The red **X** indicates that data is necessary and defines the case. In order to solve the 3D-mass balance, the particle tracking module of HSC is required. This is currently available only for AMIRA P9O Sponsors.*

Assayed or estimated values | Case |	1D Components	1D Assays	1D Minerals	1.5D	2D Assays	2D Minerals	3D
Total stream flowrates	X						
Total solid flowrates	X	X	X	X	X	X	X
Liquid flowrates	X				(X)	(X)	(X)
Component flowrates	**X**						
Component distributions	X						
%Solids		(X)	(X)	(X)	(X)	(X)	(X)
Bulk chemical compositions		**X**	X		X	X	X
Minerals and their chemical composition			**X**			**X**	X
Particle size distribution				**X**	X	X	X
Chemical composition of size fractions					**X**	**X**	X
Particles (MLA data)							**X**

48.2. Mass balancing steps in HSC 7

The mass balancing steps of HSC 7 are:

1. Open HSC Sim and change to Experimental Mode (see manual “47 Sim Experimental”)
2. Draw the flowsheet (see manuals “40 Sim Flowsheet” and “47 Sim Experimental”)
   - You can draw all the streams and units. HSC will create the mass balance equations according to the available data; therefore there is no need to draw the flowsheet for mass balancing only, or every time a new flowsheet for different kinds of mass balance problems
   - When giving the names for the streams, use the very same names as in your analysis lists
3. Bring in the experimental data (see manual “47 Sim Experimental”)
   - The data is collected in an Excel file
   - The structure can be horizontal or vertical, i.e. each stream is a row (horizontal) or a column (vertical)
   - The name of the stream must match with the drawing
   - There is no need to make a row/column for each stream, only the one where you have data. You can also have extra streams or extra information not be used in mass balancing
   - You can have various data sets - place each of them in separate sheets
4. Go through the mass-balancing wizard
   - Step 1: HSC identifies the data according to extensions; if identification fails you need to tell which type of data you have. You can include or exclude part of the data according to your wish.
   - Step 2: Define the streams to be included in creating mass balance equations. The default is that all streams are included. If you want to mass balance only part of the circuit, you can just unselect the streams you want to exclude
   - Step 3: Give an error model and standard deviation for each measurement or estimate
   - Step 4: Define the feed stream, against which the recovery calculations will be made
   - Step 5: Check the mass balance nodes and possible errors in the data indicated by HSC
5. Run the mass balance
   - You can fine tune your error models and define a sampling error for each stream individually
   - You can select different solution methods (least squares, MinMax, non-negative least squares, constrained least squares)
   - Balanced values are reported with indicator showing if the balanced result deviates from the measured one significantly (more than one standard deviation)
6. Report the results
   - Mass balance report
   - Visualizing measured, balanced, standard deviation, difference, relative difference, recovery, minimum and maximum values in flowsheet as Sankey diagrams or as stream tables
   - Studying the weighted sum of squares WSSQ on the flowsheet
   - Plotting Parity Charts
   - Plotting Difference Charts

7. Saving the mass balance template
   - Saving the mass balance template to be used later in mass balancing new sample sets from the circuit

48.3. Drawing the flowsheet

Basically you draw your flowsheet as you normally do in HSC Sim, the only exception is that you should change the mode to the Experimental Mode (see manual "47 Sim Experimental"). For drawing the flowsheet see manuals "40 Sim Flowsheet" and "47 Sim Experimental."

You can draw all the streams and units. HSC will create the mass balance equations according to available data; therefore there is no need to draw a flowsheet for mass balancing only or every time a new flowsheet for different kinds of mass balance problems.

When giving the names for the streams, use the identical names as in your analysis lists. Before proceeding, please check the stream connections and check flowsheet for possible errors (see manual "47 Sim Experimental")

48.4. Organizing the experimental data in HSC

When the flowsheet is ready (i.e. all streams are named properly and connections have been checked) you can bring in your experimental data. The following section will concentrate on how to bring the data for mass balancing and data reconciliation. For more information on how to use experimental data in HSC Sim, please see manual "47 Sim Experimental."

The easiest way is to first generate the experimental sheets with HSC Sim.

- Select from the menu Experimental – Analyses
- From the menu select Create – Stream Properties Sheet – Horizontal (optionally you can select Vertical, Horizontal with Multiple Size Fractions, Horizontal with Multiple Cases) (Figure 1).
- HSC Sim will create a sheet named "Streams" and list all the Streams, their Sources and Destinations and generate the standard columns: Solids Recovery%, Total Solids t/h, FractionNo, Fraction name, Fraction m% and Note.

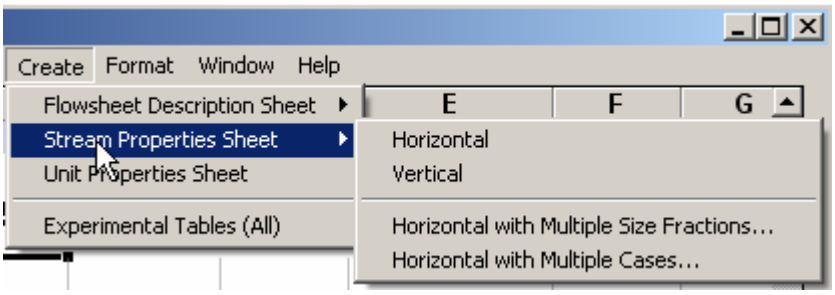


Figure 1. Create Stream Properties Sheet, using preferentially horizontal data.

Experimental Data

File Edit Tools Data Graphics Model Create Format Window Help

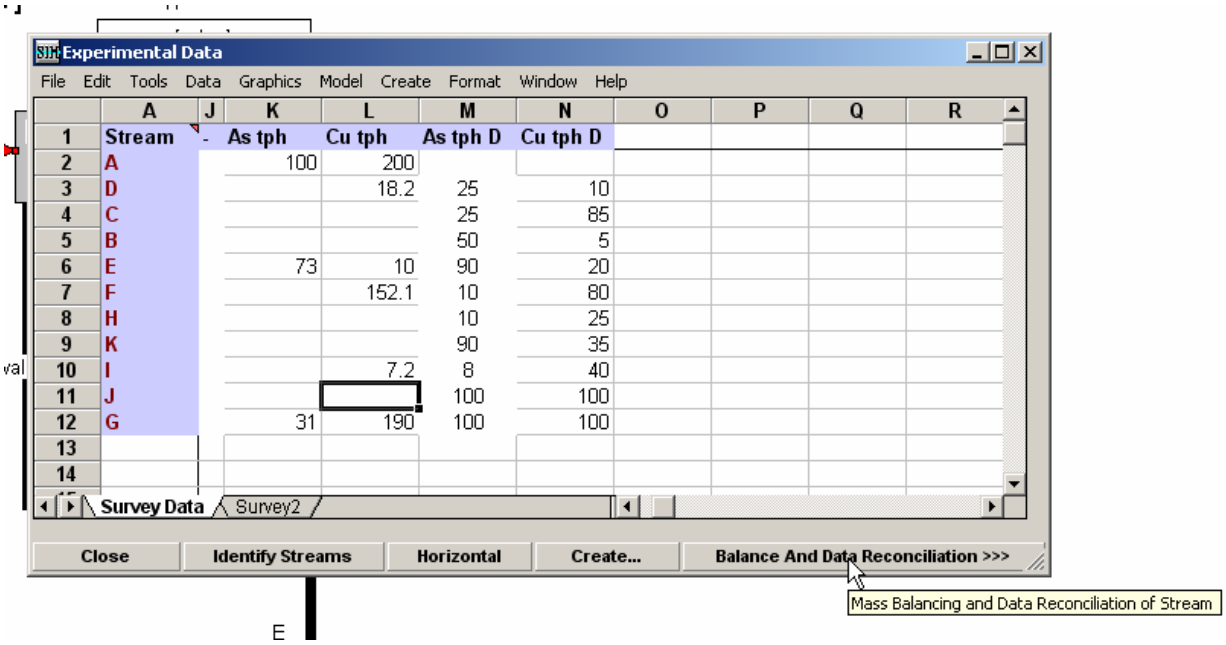
	A	B	C	D	E	F	G	H	I	J
1	Stream	Source	Destination	Solids Recovery%	Total Solids t/h	FractionNo	Fraction nam	Fraction m%	Note	-
2	ROM	?	SAG			0	Bulk			
3	SAG Discharge	SAG	Cyclone			0	Bulk			
4	Cyclone UF	Cyclone	SAG			0	Bulk			
5	Cyclone OF	Cyclone	Rougher			0	Bulk			
6	RC	Rougher	1st Cleaner			0	Bulk			
7	CC1	1st Cleaner	2nd Cleaner			0	Bulk			
8	Final Concentrat	2nd Cleaner	?			0	Bulk			
9	RT	Rougher	Scavenger			0	Bulk			
10	SC	Scavenger	1st Cleaner			0	Bulk			
11	Final Tail	Scavenger	?			0	Bulk			
12	CT2	2nd Cleaner	1st Cleaner			0	Bulk			
13	CT1	1st Cleaner	Scavenger			0	Bulk			
14	Mill Water	Process Waters	SAG			0	Bulk			
15	Mill Sump Water	Process Waters	Cyclone			0	Bulk			
16										
17										

Figure 2. HSC Sim creates a sheet called "Streams" and lists all the streams, their Source and Destination and generates the standard columns.

- Organize your assays in Excel (or some other spreadsheet program):
  - row-wise (each stream is one row)
  - the first column gives the name of the stream
  - one header row
  - the name for the first column with stream names must be "Stream"
  - the order of the stream can be whatever
  - some streams can be missing
  - the following columns gives the experimental data, for example, assays, use syntax element-separator-method-separator-unit (e.g. Cu XRF % (space is separator)). You can leave method out if you like (e.g. Cu %, Au ppm).
  - HSC will identify the type of the experimental data from the extension:
    - Use **%**, **ppm** or **g/t** for chemical assays (e.g. Cu %)
    - Use **t/h**, **tph** for flowrates (e.g. Cu tph)
    - Use **D** for distribution (e.g. "Cu % D")
    - Use **SD** for standard deviation (e.g. Cu % SD)
    - Use **RSD%** for relative standard deviation (e.g. Cu % RDS%)
    - If you use some other syntax, HSC does not recognize the type automatically and you need to specify the type manually
- Copy and paste the data
  - Once the data is organized, select it in Excel, and the "Stream" cell must be the top left cell, and copy to the clipboard
  - Go the HSC Sim Analyses and select from the menu Edit – Paste Special Assays
  - Save your data (file save), HSC Sim will create a file named "Assays.xls" in the same folder as the flowsheet, see the window title for full path.
- You can have different mass balance cases (surveys) on different sheets. Rename the "Streams" sheet by double-clicking and typing a new name. Then you can generate a new sheet and bring in new data. Optionally, you can open the file in Excel and organize your data there. When ready, reopen the file in HSC Sim.

48.5. Mass Balance Wizard

Once the experimental data is ready in HSC Sim you can start the mass balancing and data reconciliation by pressing "**Balance and Data Reconciliation >>>>"** in the lower right corner of the "Experimental Data" window (Figure 3). Please remember that **HSC Sim uses the data of the current spreadsheet**. Please check that the active sheet is the right one.



	A	K	L	M	N
1	Stream	As tph	Cu tph	As tph D	Cu tph D
2	A	100	200		
3	D		18.2	25	10
4	C			25	85
5	B			50	5
6	E	73	10	90	20
7	F		152.1	10	80
8	H			10	25
9	K			90	35
10	I		7.2	8	40
11	J			100	100
12	G	31	190	100	100
13					
14					

Figure 3. Starting the Mass Balancing and Data Reconciliation.

Now you are supposed to go through the Wizard with five steps. You can skip the wizard by pressing **Skip Wizard** in any step of the wizard.

48.5.1. Step 1: Select Components and Analyses

In the first step, you can define the components to be selected in the mass balance equation and you define their types.

- Click the second column to change between the selected (**X**) and not selected ( ) (Figure 4)
- Click the row and you can see the variation of selected element (if selected, i.e. the second column has the **X**) in the flowsheet as a Sankey diagram (Figure 5).
- Check the variable type (third column).
- If the variable type (third column) is wrong, define the type using the combo-box below. The options are:
  - Solids flowrate (SF)
  - Water flowrate (WF)
  - Percent solids (weight/weight) (%S)
  - Assays (A)
  - Fraction mass percentage (FM%)
  - Fraction name (FN) (will be excluded in mass balancing)
  - Fraction number (F#) (will be excluded in mass balancing)
  - Assay of the fraction mass (AFM%)

- Component flowrate (CF)
- Component distribution (CD)
- Other (O); this type will be excluded in the mass balancing

- The following column gives data minimum (Min), maximum (Max), and the number of streams with data (NOM). **If both the minimum and maximum are zero, HSC Sim will turn the component to non-selected.** (min and max number are yellow and min has a comment "both min and max are zero").

Press for quick information of the window.

Press **Next** to proceed to the next step.

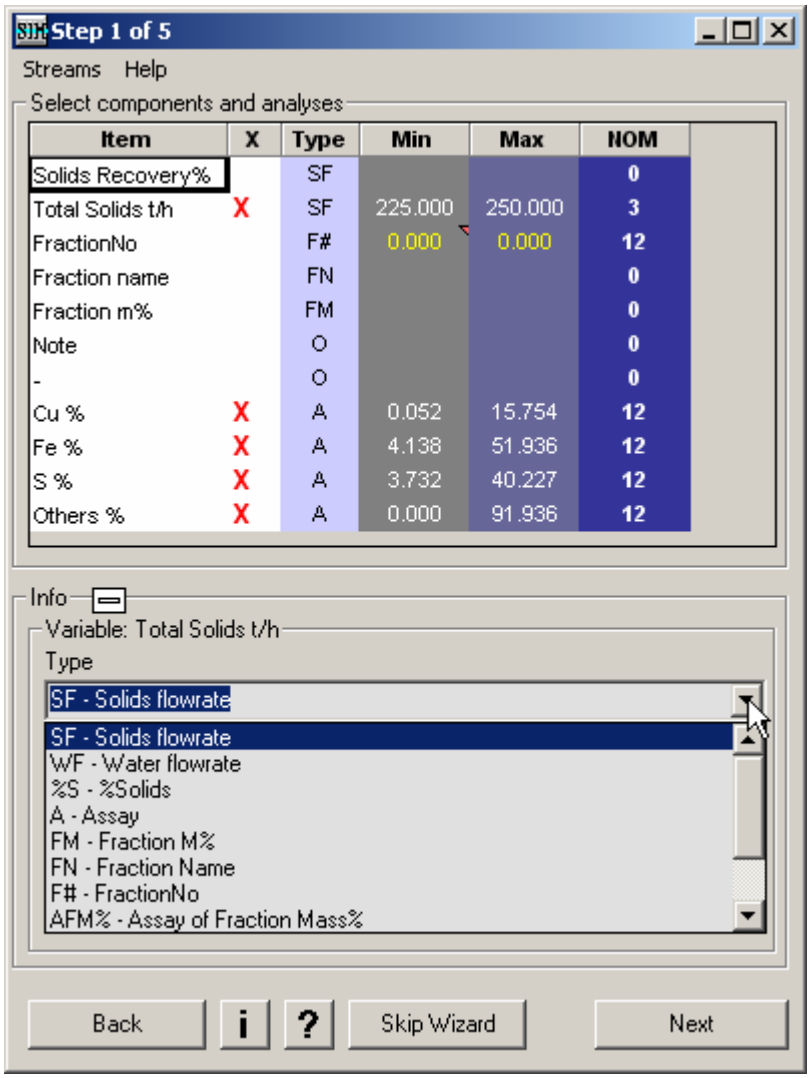


Figure 4. Step 1:

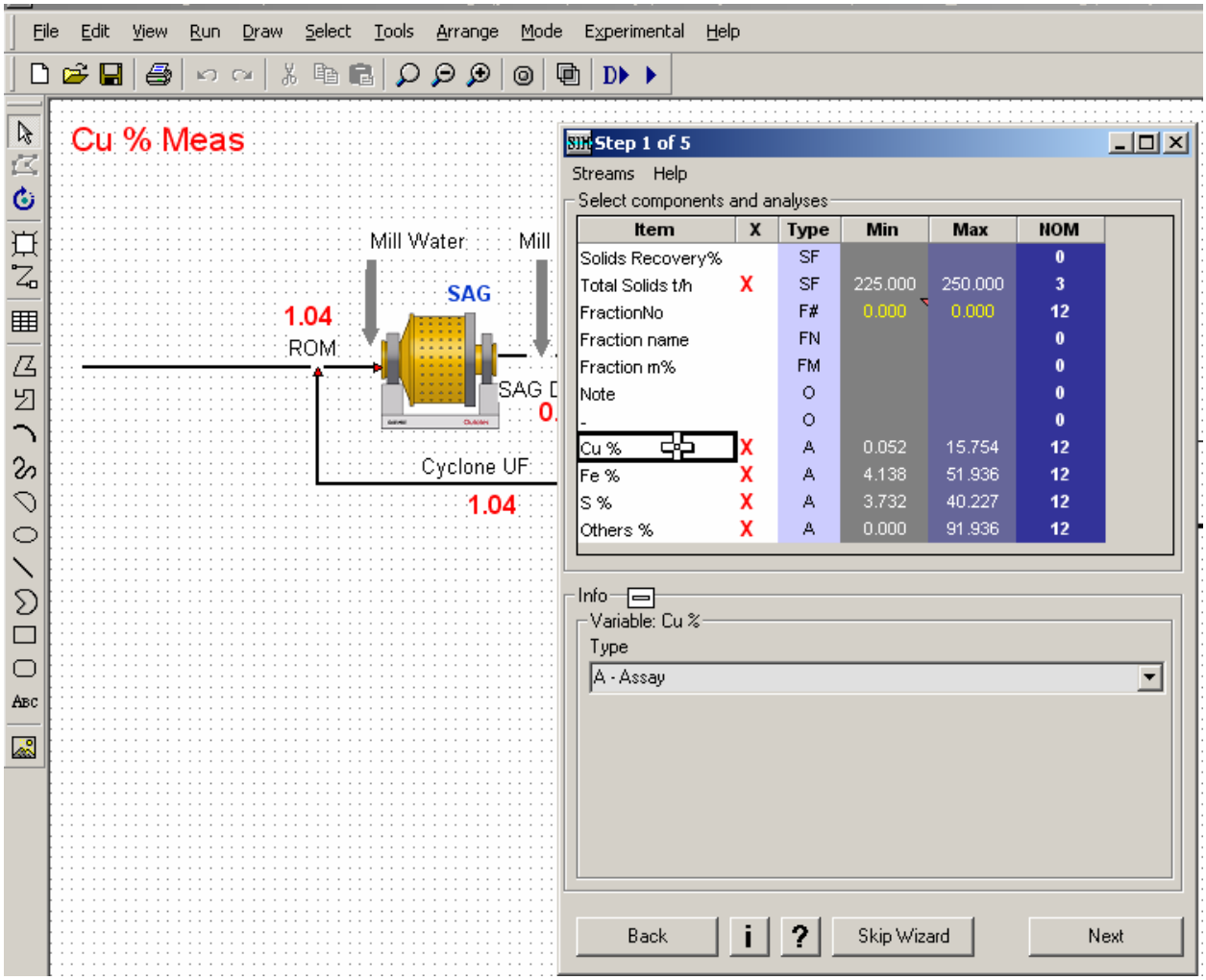


Figure 5. Selecting a row will generate a Sankey diagram, i.e. showing the variation of currently selected component in the streams with the thickness of the stream.

48.5.2. Step 2: Define Streams to be included in Mass Balancing

In the second step you can exclude some of the streams in the mass balance equation. Uncheck the stream in the list or click the stream in the flowsheet. Click again to select the stream back.

Unselecting the stream in mass balancing equals the case where the current stream does not exist in the drawing at all. Most commonly you may exclude some streams if:

- you want to balance only part of the circuit
- you have drawn optional connections in the circuit and those streams are not active in the current mass balancing
- you are mass balancing only solids; in that case you need to make pure liquid (water) streams inactive

Avoid making a stream inactive if you do not have assays of the current stream but you want to mass balance streams both upstream and downstream.

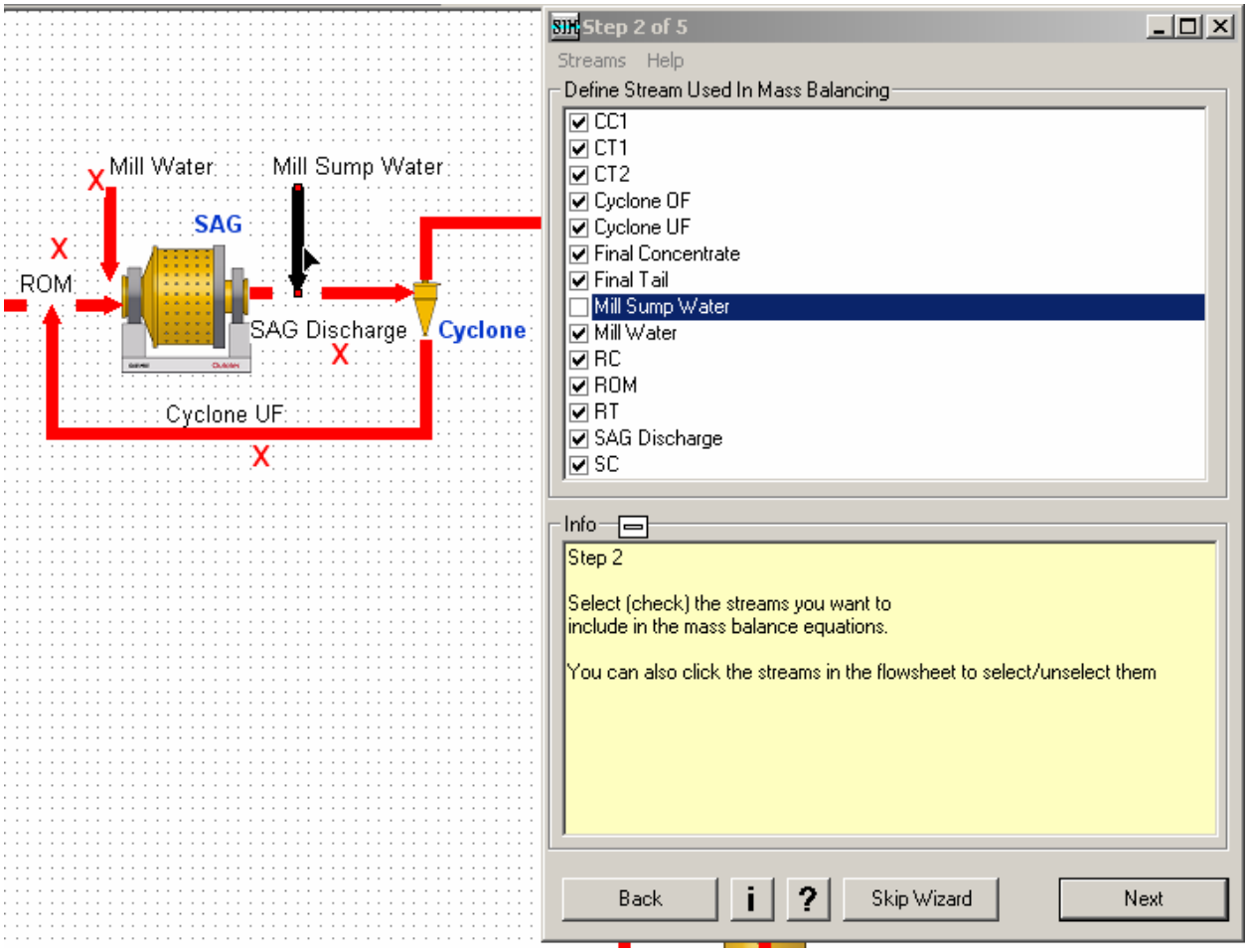


Figure 6. Excluding mill sump water in mass balancing.

48.5.3. Step 3: Define Error Models

Each assay and raw data is subject to errors. Mass balancing and data reconciliation is meant for adjusting the unreliable values whereas the reliable values should be adjusted only a little, if at all. Therefore, the user has to give a value to how reliable each item of raw data is. This is done by defining the Error Model.

In the Step 3 Wizard window, all the components selected in the mass balancing (in Step 1) are listed (Figure 7). Again the minimum, maximum, and number of streams with data are listed. Activating the row will visualize the component in the Sankey diagram.

The second column gives the Error Model parameters (i.e. standard deviation), the third shows the type (as listed in Step 1) and the fourth gives the error model. The Error Models available are (see Figure 8):

Error Model	Parameters	Example
Fixed	Fixed standard deviation as plain number or fixed relative standard deviation as negative number or in parenthesis	0.1 -5, (5)
X.x = X%+0.x	Integer part is the relative standard deviation, decimal part is the detection limit	10.1
X%+0.1	Given parameter is the relative standard deviation,	6

	0.1 is the detection limit	
10%+X	Parameter is the detection limit, relative standard deviation is fixed 10%	0.05
a;b;c = MIN(a%+b;c)	a is the relative standard deviation, b is the detection limit and c is the maximum standard deviation	10;0.01;0.5
a;b;c=MAX(a%+b;c)	a is the relative standard deviation, b is the detection limit and c is the minimum standard deviation	10;0.02;0.2
a;b;c=%;MIN;MAX	a is the relative standard deviation, MIN is minimum standard deviation and MAX is the maximum standard deviation	10;
Data	Standard deviation is given in data individually for each stream	

Select the Error Model using the Combo Box and write error model parameters in the text box below (Figure 7). Use the Show Graph button to see the error model graphically (Figure 8).

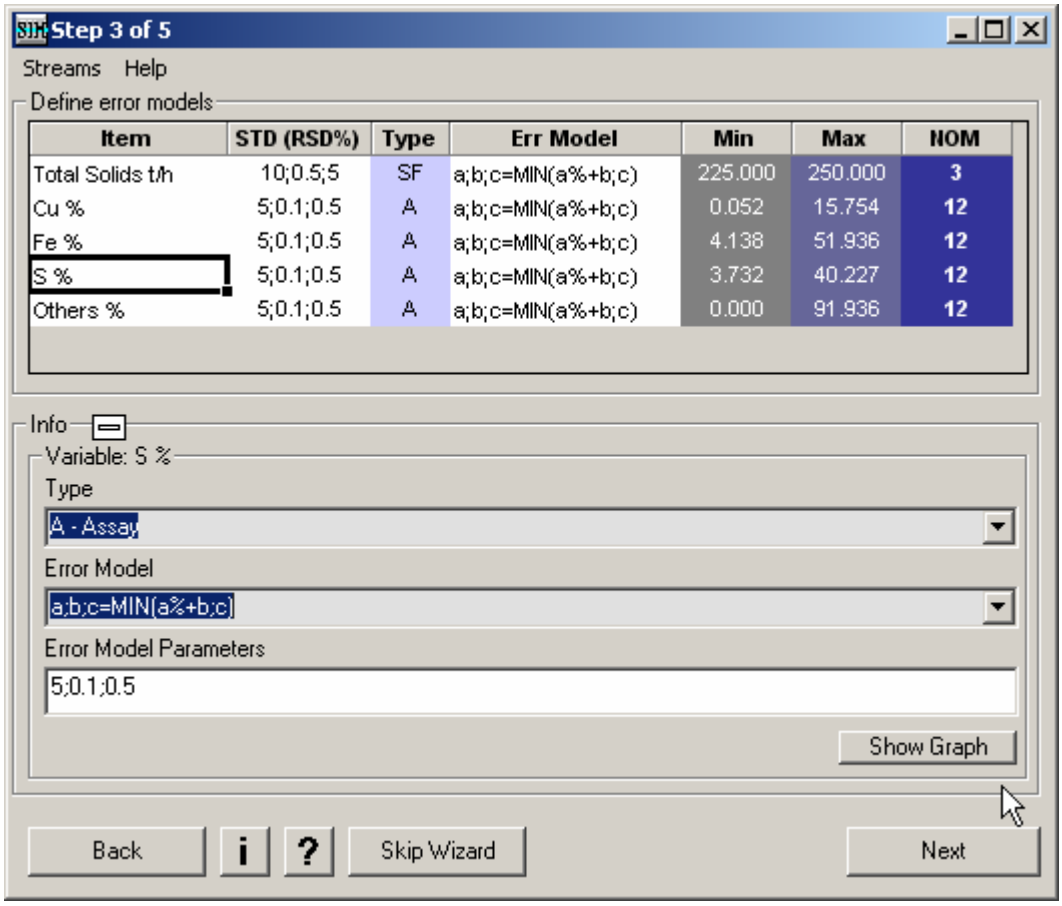


Figure 7. Step 3: Define the Error Model.

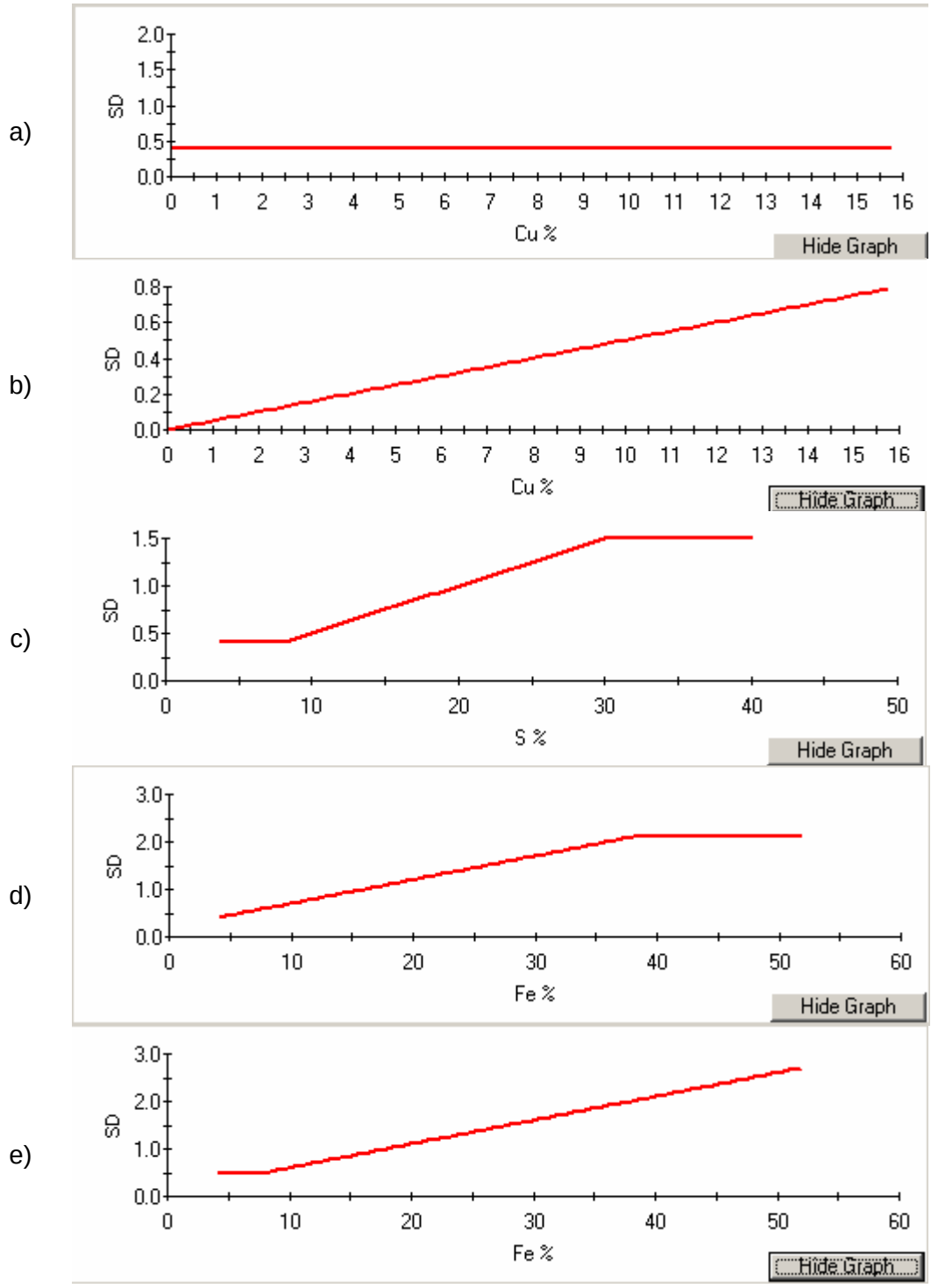


Figure 8. Error models. a) Fixed absolute (0.4), b) Fixed relative (5%), c) a;b;c=%;MIN;MAX; (5;0.4;1.5), d) a;b;c=MIN(a%+b;c) (5;0.5;2.1), e) a;b;c=MAX(a%+b;c) (5;0.5;2.1).

To find out which error model you should use, please do some duplicate assays. Most laboratories, however, know their detection limits and relative standard deviations. Quite often the standard deviation does not increase any more linearly when reaching the “easy assay range” (see Figure 8c). Quite often these types of error models are the most applicable

ones (i.e. the ones shown in Figure 8c and 8d). Type a;b;c=MIN(a%+b;c) is the default for assays (Figure 8).

Avoid mixing the assay error and sampling error. You can define the sampling error for each stream individually finally when you have completed steps 1-5 in the Wizard. **The final standard deviation is the sum of the sampling error and assay error**; see chapter 48.6.

48.5.4. Step 4: Define the Reference Stream

In the fourth step, you must define the reference stream. This is the stream against which the recoveries are calculated. Normally this is a feed stream. If there are several feed streams, you can define only one reference stream (in version 7.0).

To define the reference stream, check the stream in the list box or directly in the flowsheet.

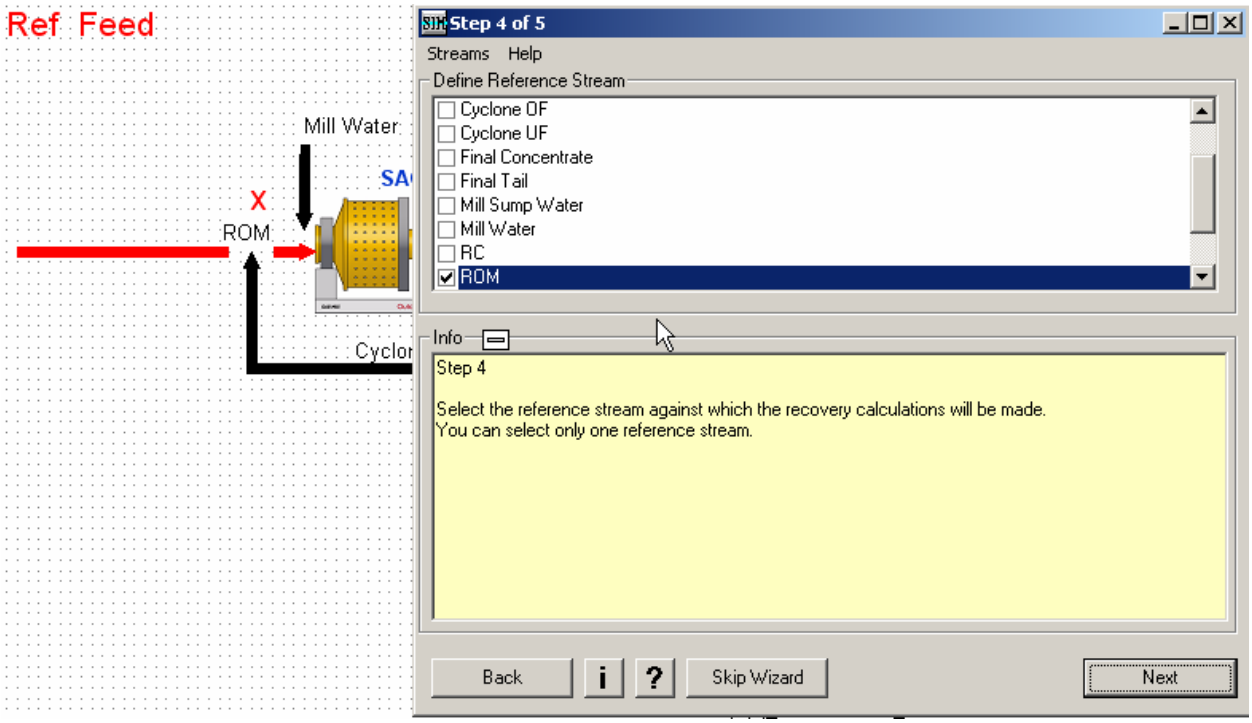


Figure 9. Step 4 of 5. Define the Reference stream.

48.5.5. Step 5: Check Mass Balance Nodes and Possible Errors

In the final 5th step you should check the mass balance nodes and go through the possible errors HSC Sim has found in the raw data (Figure 10).

Based on the assays available, HSC Sim will create mass balance nodes. If a stream does not have any measurements, then the size of the mass balance node is increased. You can check the mass balance node by activating the mass balance node and checking the inputs and outputs of the node on the flowsheet: blue is used for input streams (of the node), red for output streams (of the node), thick black nodes are streams within the node (but cannot be

solved directly due to missing data) and thin black nodes are not included in the mass balance node. See Figures 11 and 12 for examples.

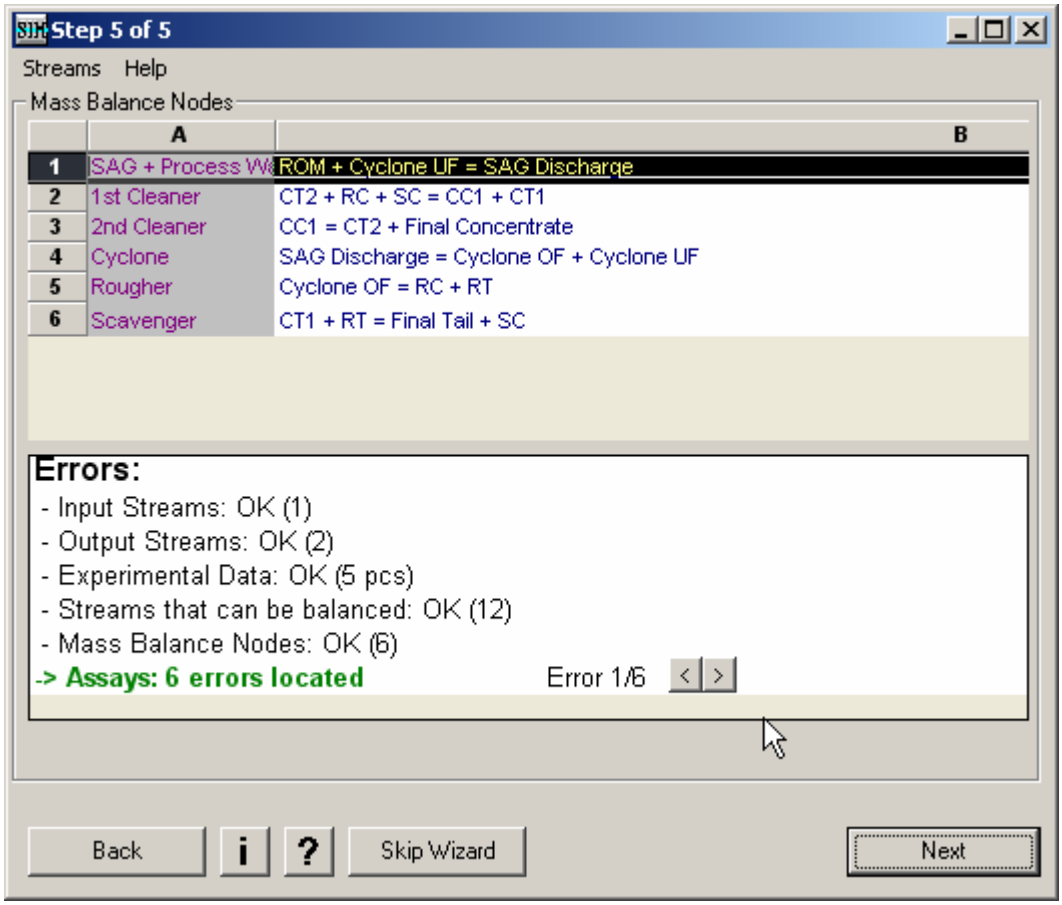

Step 5 of 5
Streams Help
Mass Balance Nodes
A
B
1 SAG + Process Wa ROM + Cyclone UF = SAG Discharge
2 1st Cleaner CT2 + RC + SC = CC1 + CT1
3 2nd Cleaner CC1 = CT2 + Final Concentrate
4 Cyclone SAG Discharge = Cyclone OF + Cyclone UF
5 Rougher Cyclone OF = RC + RT
6 Scavenger CT1 + RT = Final Tail + SC
Errors:
- Input Streams: OK (1)
- Output Streams: OK (2)
- Experimental Data: OK (5 pcs)
- Streams that can be balanced: OK (12)
- Mass Balance Nodes: OK (6)
-> Assays: 6 errors located
Error 1/6
Back
i
?
Skip Wizard
Next

Figure 10. Fifth step of the Mass Balancing Wizard. Check the mass balance nodes and possible errors.

Errors mean that the assayed values of input streams are out of the range of the output streams (see Figure 13). By going through the errors you may find some bad samples that you may even turn off in the mass balancing or you may assign a high sampling error. In the same way, you may find that some component (assay) has more errors. Again you may end up by turning that component off in mass balancing or then you may assign a high standard deviation for the component. You can often find errors in components whose grades are low and close to the detection limit.

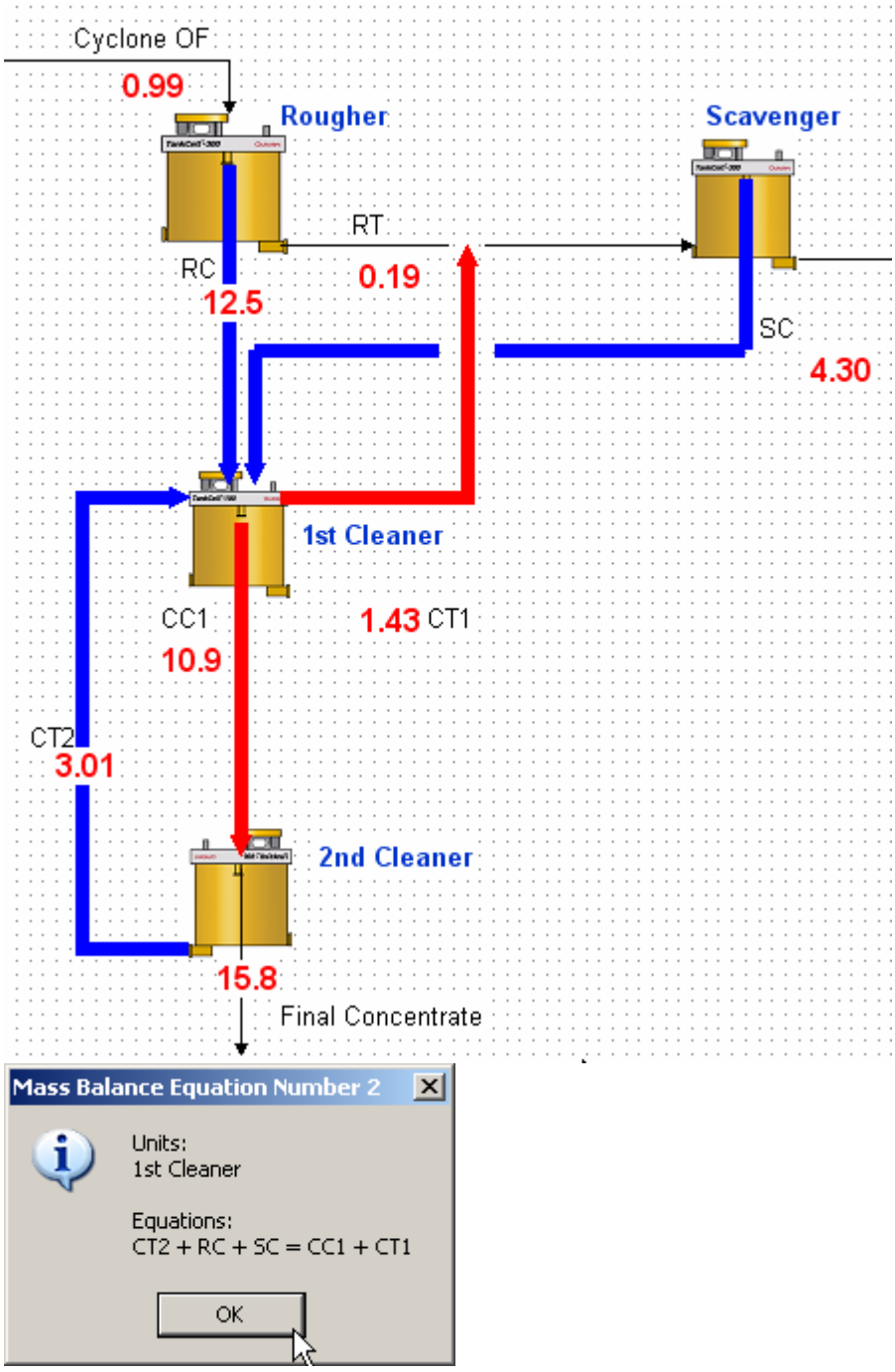


Figure 11. Example of a mass balance node: 1st Cleaner. Input streams are shown as blue streams and output streams as red streams.

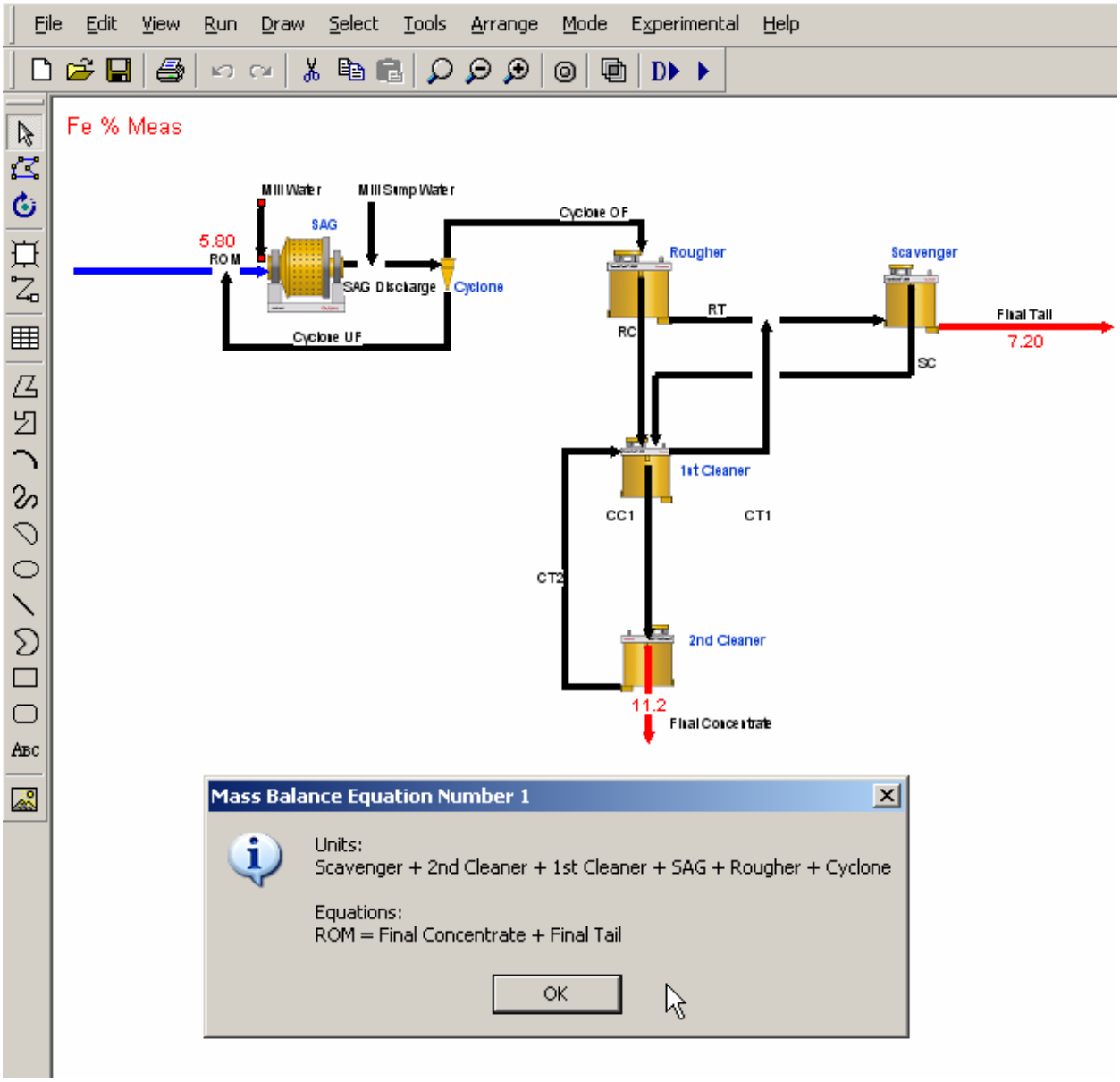


Figure 12. Example of a mass balance case where only three streams have been sampled and assayed and HSC creates only one mass balance node.

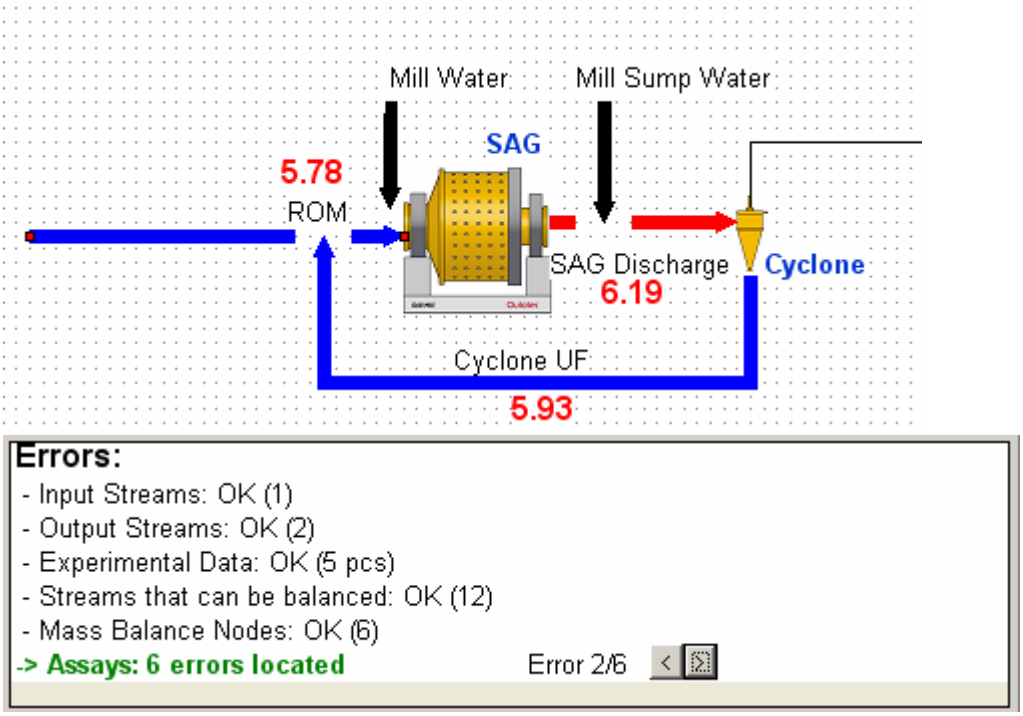


Figure 13. Example of an error. Sulfur in the output of the SAG is higher than in both of the input streams.

48.6. Mass Balance Window

After completing the Mass Balance Wizard steps you will come to the Mass Balance and Data Reconciliation Window (Figure 14). On the left-hand side you will see the **Navigator**: buttons to navigate between different sub-windows. In the middle you have the **Data Sheet**. On the right-hand side you can see the **Balance/Report Options**. To solve the mass balancing problem press the 6. Run Balancing or Balance And Reconcile ! button.

The Navigator (Figure 15) can be minimized by using the button. With the navigator you can navigate between different sub-windows, which are for redefining some of the issues defined already when using wizards. The various controls of the Navigator are shown and explained in Figure 15.

The Data Sheet (Figure 16) shows the mass balancing data in a table. Each stream is one row. Each component selected in mass balancing is listed from left to right. Each component has the following columns from left to right (Figure 18):

- Measured (Meas; white column)
- Standard deviation (SD (RSD%); blue column)
- Minimum (Min, yellow column)
- Maximum (Max, pale blue)
- Balanced (Bal, grey)
- Absolute difference (Diff%, orange)
- Relative difference (RDiff%, pale green)

- Recovery (Rec%, blue)

The visibility of the columns is controlled on the right-hand side in Balance/Reporting Options (Figure 19).

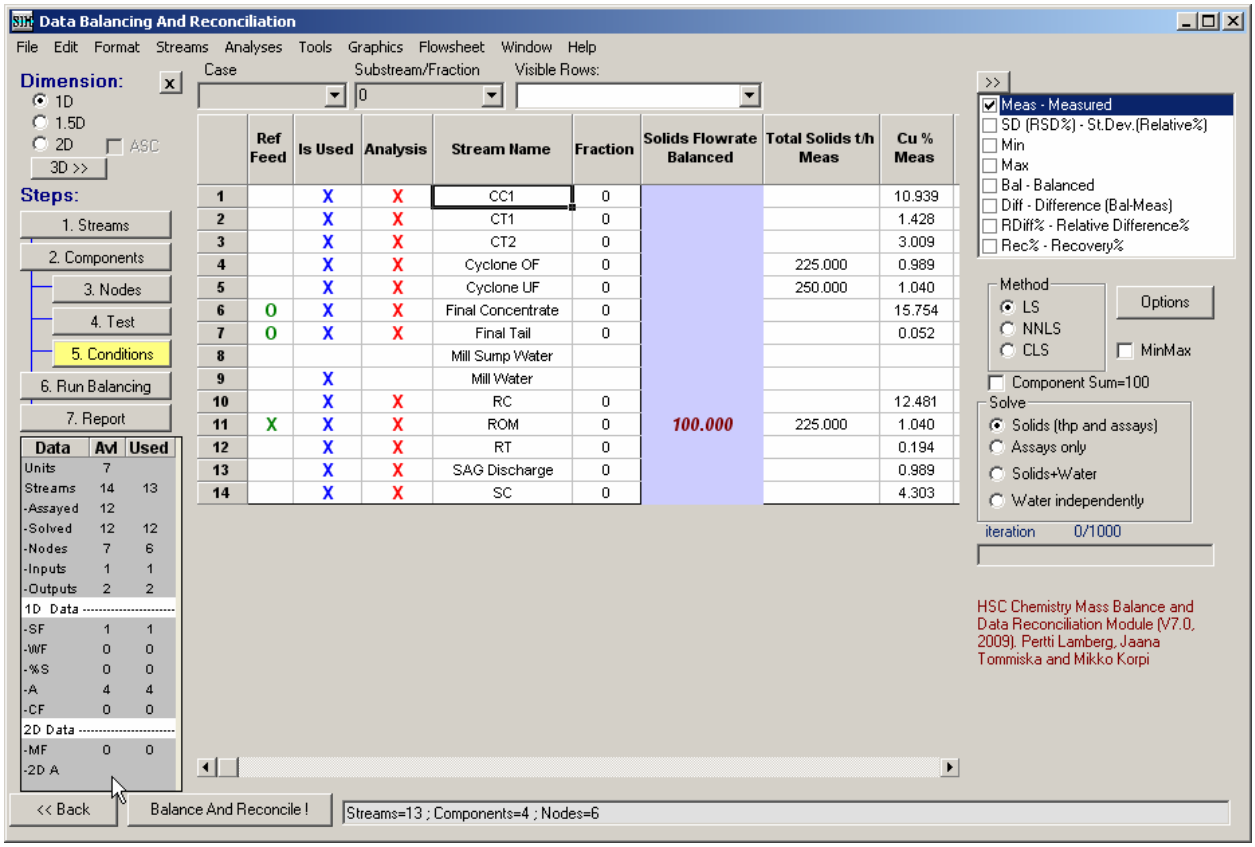


Figure 14. Mass Balancing and Data Reconciliation window. Navigator on the left, Data Sheet in the middle and Balancing/Reporting options on the right.

To solve a mass balance problem, the following mathematical methods are available in the Balance/Report Options on the right-hand side:

- Least Squares Solution (LS)
- Unconstrained MinMax Solution (minimizes the maximum difference) (MinMax and UMM (Figure 19))
- Non-negative Least Squares Solution (NNLS)
- Constrained Least Squares Solution (CLS)

Mass balance problems are solved in two stages: firstly, the total mass flowrates are solved and then the assays are reconciled. In solving the assays, the least squares solution finds the best solution by minimizing the weighted sum of squares. That is

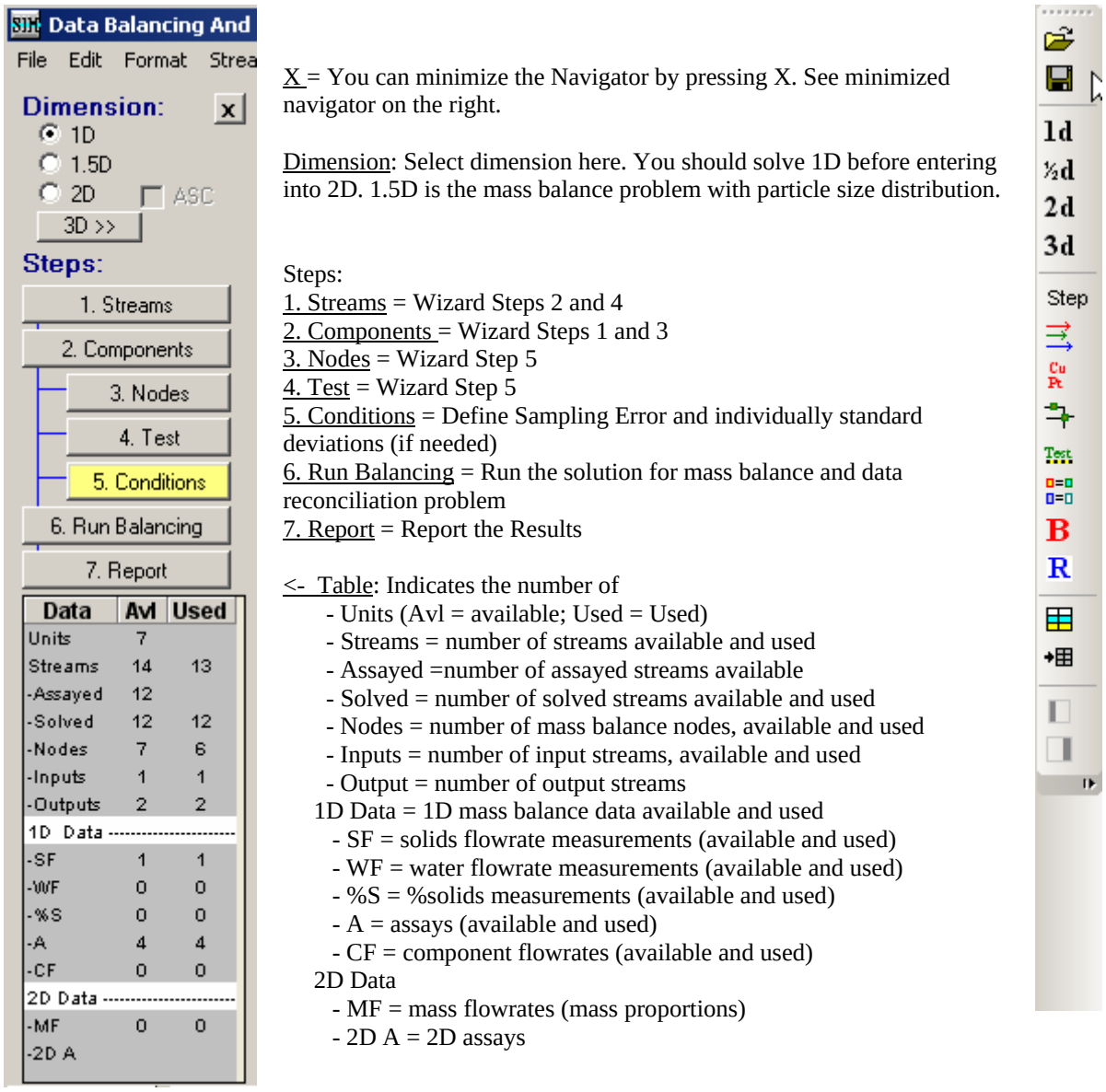
$$WSSQ = \sum_{j=1}^{k} \sum_{i=1}^{n} \frac{(a_{ij} - b_{ij})^2}{s_{ij}^2}$$

where j refers to the stream, k is the number of streams, i refers to the components (analyses), n is the number of components, a is the measured value, b is the balanced value and s is standard deviation.

In the non-negative least squares, all a's are subject to be non-negative.

In the constrained least squares all a's are subject to be between min and max.

For more details, see the mathematics in chapter 48.12.



X = You can minimize the Navigator by pressing X. See minimized navigator on the right.

Dimension: Select dimension here. You should solve 1D before entering into 2D. 1.5D is the mass balance problem with particle size distribution.

Steps:
1. Streams = Wizard Steps 2 and 4
2. Components = Wizard Steps 1 and 3
3. Nodes = Wizard Step 5
4. Test = Wizard Step 5
5. Conditions = Define Sampling Error and individually standard deviations (if needed)
6. Run Balancing = Run the solution for mass balance and data reconciliation problem
7. Report = Report the Results

<- Table: Indicates the number of
- Units (Avl = available; Used = Used)
- Streams = number of streams available and used
- Assayed =number of assayed streams available
- Solved = number of solved streams available and used
- Nodes = number of mass balance nodes, available and used
- Inputs = number of input streams, available and used
- Output = number of output streams

1D Data = 1D mass balance data available and used
- SF = solids flowrate measurements (available and used)
- WF = water flowrate measurements (available and used)
- %S = %solids measurements (available and used)
- A = assays (available and used)
- CF = component flowrates (available and used)

2D Data
- MF = mass flowrates (mass proportions)
- 2D A = 2D assays

Figure 15. Mass Balance Navigator (see Figure 14).

	Ref Feed	Is Used	Analysis	Stream Name	Fraction
1		X	X	CC1	0
2		X	X	CT1	0
3		X	X	CT2	0
4		X	X	Cyclone OF	0
5		X	X	Cyclone UF	0
6	O	X	X	Final Concentrate	0
7	O	X	X	Final Tail	0
8				Mill Sump Water	
9		X		Mill Water	
10		X	X	RC	0
11	X	X	X	ROM	0
12		X	X	RT	0
13		X	X	SAG Discharge	0
14		X	X	SC	0

Solids Flowrate Balanced	Total Solids t/h Meas	Total Solids t/h Bal	Cu % Meas	Cu % Bal	Fe % Meas	Fe % Bal	S % Meas	S % Bal	Others % Meas	Others % Bal
29.346		29.346	10.939	10.466	48.752	48.979	37.302	38.106	3.007	2.418
20.480		20.480	1.428	1.839	40.933	40.310	37.417	37.101	20.223	20.725
13.130		13.130	3.009	3.221	51.936	51.821	40.227	39.868	4.827	5.318
224.950	225.000	224.950	0.989	1.119	7.380	7.255	6.606	6.310	85.025	85.305
250.088	250.000	250.088	1.040	1.004	7.127	6.982	5.925	5.958	85.908	86.059
16.216		16.216	15.754	16.332	48.018	46.678	37.490	36.679	0.000	0.069
208.734		208.734	0.052	(0.063)	4.475	4.192	4.057	3.950	91.416	91.927
		0.000								
19.364		19.364	12.481	12.082	41.661	41.992	34.299	34.495	11.558	11.118
224.950	225.000	224.950	1.040	1.119	6.786	7.255	5.784	6.310	86.389	85.305
205.587		205.587	0.194	0.086	4.138	3.983	3.732	3.655	91.936	92.292
475.038		475.038	0.989	1.058	6.836	7.111	6.187	6.124	85.988	85.702
17.333		17.333	4.303	3.955	43.789	44.389	39.350	39.617	12.557	12.133

Figure 16. Data Sheet. Above = left part of the Data Sheet. Below = Measured and Balanced columns visible.

Solids Flowrate Balanced	Sampling Err%	Total Solids t/h Meas	Total Solids t/h SD (RSD%)	Total Solids t/h Bal	Cu % Meas	Cu % SD (RSD%)	Cu % Bal
29.346	0.00		5.000	29.346	10.939	0.400	10.466
20.480	0.00		5.000	20.480	1.428	0.400	1.839
13.130	0.00		5.000	13.130	3.009	0.400	3.221
224.950	0.00	225.000	5.000	224.950	0.989	0.400	1.119
250.088	0.00	250.000	5.000	250.088	1.040	0.400	1.004
16.216	0.00		5.000	16.216	15.754	0.400	16.332
208.734	0.00		5.000	208.734	0.052	0.400	(0.063)
	0.00		5.000			0.400	
	0.00		5.000	0.000		0.400	
19.364	0.00		5.000	19.364	12.481	0.400	12.082
224.950	0.00	225.000	5.000	224.950	1.040	0.400	1.119
205.587	0.00		5.000	205.587	0.194	0.400	0.086
475.038	0.00		5.000	475.038	0.989	0.400	1.058
17.333	0.00		5.000	17.333	4.303	0.400	3.955

Cu % Meas	Cu % SD (RSD%)	Cu % Min	Cu % Max	Cu % Bal	Cu % Diff	Cu % RDiff%	Cu % Rec%
10.939	0.400			10.466	-0.47	-4.4	122.0
1.428	0.400			1.839	0.41	25.2	15.0
3.009	0.400			3.221	0.21	6.8	16.8
0.989	0.400			1.119	0.13	12.3	100.0
1.040	0.400			1.004	-0.04	-3.6	99.7
15.754	0.400			16.332	0.58	3.6	105.2
0.052	0.400			(0.063)	-0.11	2038.2	-5.2
	0.400						
	0.400						
12.481	0.400			12.082	-0.40	-3.3	93.0
1.040	0.400			1.119	0.08	7.3	100.0
0.194	0.400			0.086	-0.11	-76.8	7.0
0.989	0.400			1.058	0.07	6.8	199.7
4.303	0.400			3.955	-0.35	-8.4	27.2

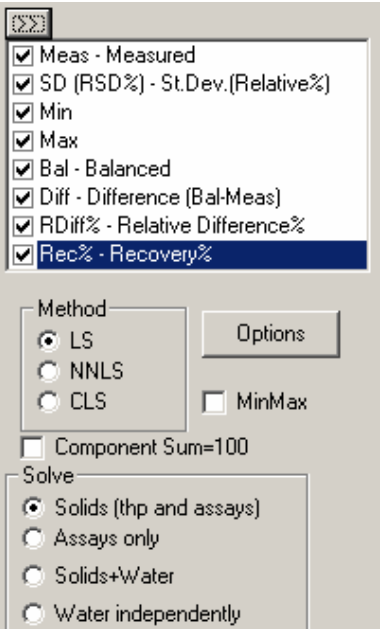
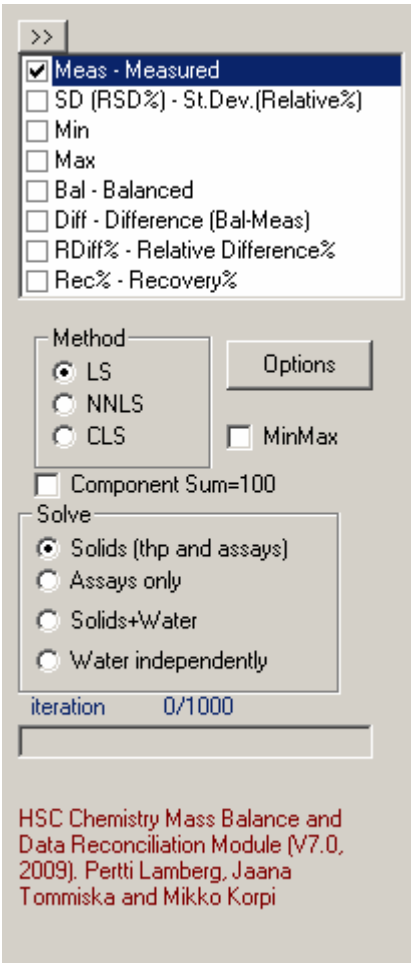


Figure 17. Above: Bottom = Measured, Standard Deviation and Balanced columns visible. Below: All items are selected to be visible in the Data Sheet. Please note that each column is different in color to help its identification.



>> Use for minimizing the Balancing/Reporting Options

Selector: Use to hide or unhide the columns in the Data Sheet.
Meas = Measured values,
SD = Standard Deviation,
Min = Minimum values,
Max = Maximum values,
Bal = Balanced values,
Diff = Absolute difference between balanced and measures,
RDiff% = Relative difference between measured and balanced ones,
Rec% = Recovery against the Reference Stream.

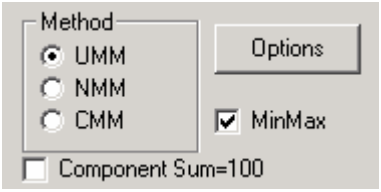
Method: LS = Least Squares
NNLS = Non-negative least squares
CLS = Constrained Least Squares
MinMax = MinMax method (see Figure 19)

Options: See figure 20

Component Sum = 100. Additional constraint, the component sum is 100%.

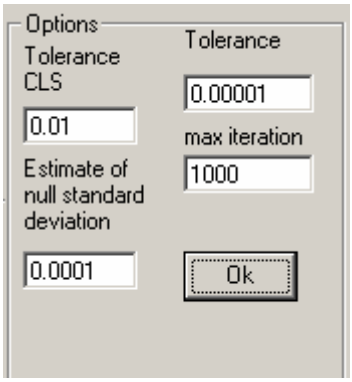
Solve:
Solids (tph and assays) = solves both solids flowrates and assays
Assays only = uses given flowrates and reconciles assays accordingly
Solids + Water = Balance for solids and water is solved simultaneously
Water independently = Solids mass balance is solved first followed by water mass balance which does not change any more solids mass balance

Figure 18. Balancing/Reporting Options.



When MinMax is checked then the methods are:
UMM = Unconstrained MinMax (Chebyshev)
NMM = Non-negative MinMax (Chebyshev) (not available in HSC 7.0)
CMM = Constrained MinMax (Chebyshev) (not available in HSC 7.0)

Figure 19. Methods available when MinMax is checked.



Tolerance = Iteration is regarded as converged when this limit is reached.
Tolerance CLS = constraints are min - tolerance <= x <= max + tolerance.

Estimate for null standard deviation = Value that is used if the standard deviation value is missing or if it is zero

max iteration = Maximum number of iterations in solving the problem .

Figure 20. Additional options.

Once you hit the 6. Run Balancing or Balance And Reconcile ! button, HSC Sim solves the mass balance problem according to your specifications. Running the mass balance will always bring the balanced (Bal) column visible. HSC Sim uses Comment Colors to indicate that the balanced value differs significantly from the measured one (Figure 21).

- Green Comment Symbol (3.029) indicates that the balance value differs more than 1*standard deviation (1SD) from the measured one.
- Yellow Comment Symbol (15.774) indicates that the difference is greater than 2SD
- Red Comment Symbol (1.135) indicates that the difference is greater than 3SD. The comment texts shows the difference compared to SD (as integers).

Cu % Meas	Cu % SD (RSD%)	Cu % Bal
10.939	0.010	10.889
1.428	0.010	1.428
3.009	0.010	3.029
0.989	0.010	1.135
1.040	0.010	1.040
15.754	0.010	15.774
0.052	0.010	(0.083)
	0.400	
	0.400	
12.481	0.400	12.092
1.040	0.400	1.135
0.194	0.400	0.125
0.989	0.400	1.085
4.303	0.400	3.939

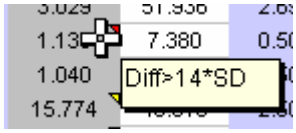


Figure 21. Comment Symbol colors are used to indicate if the balanced value differs significantly from the measured one. Green = difference > 1SD; Yellow = difference > 2SD; red = difference >3SD (true difference shown in comment text). The red color in parentheses indicates a negative solution. Try to use non-negative least squares or constrained least squares solution.

Double-clicking anywhere on the Data Sheet will render HSC Mass Balance & Data Reconciliation Dialog visible (Figure 22). HSC Sim will show the stream which was double-

clicked in the Data Sheet (i.e. the active row) in the Stream View. You can change the stream from the Combo Box on the bottom of the window. You can change the measured values, standard deviation, minimum, and maximum values. To use changed values press "Apply" and to solve them with new conditions press the "Balance" button. If you are using Min and Max values they become active only in the Constrained Least Squares solution (CLS).

To change from Stream View to Element View (in the HSC Mass Balance & Data Reconciliation Dialog) double-click on any element visible in the Stream View (i.e. in rows 8, 9, 10 …). You can change the element in the combo-box located in the bottom part of the window. In the Element View you cannot do changes here; change back to Stream View or make the changes on the Data Sheet.

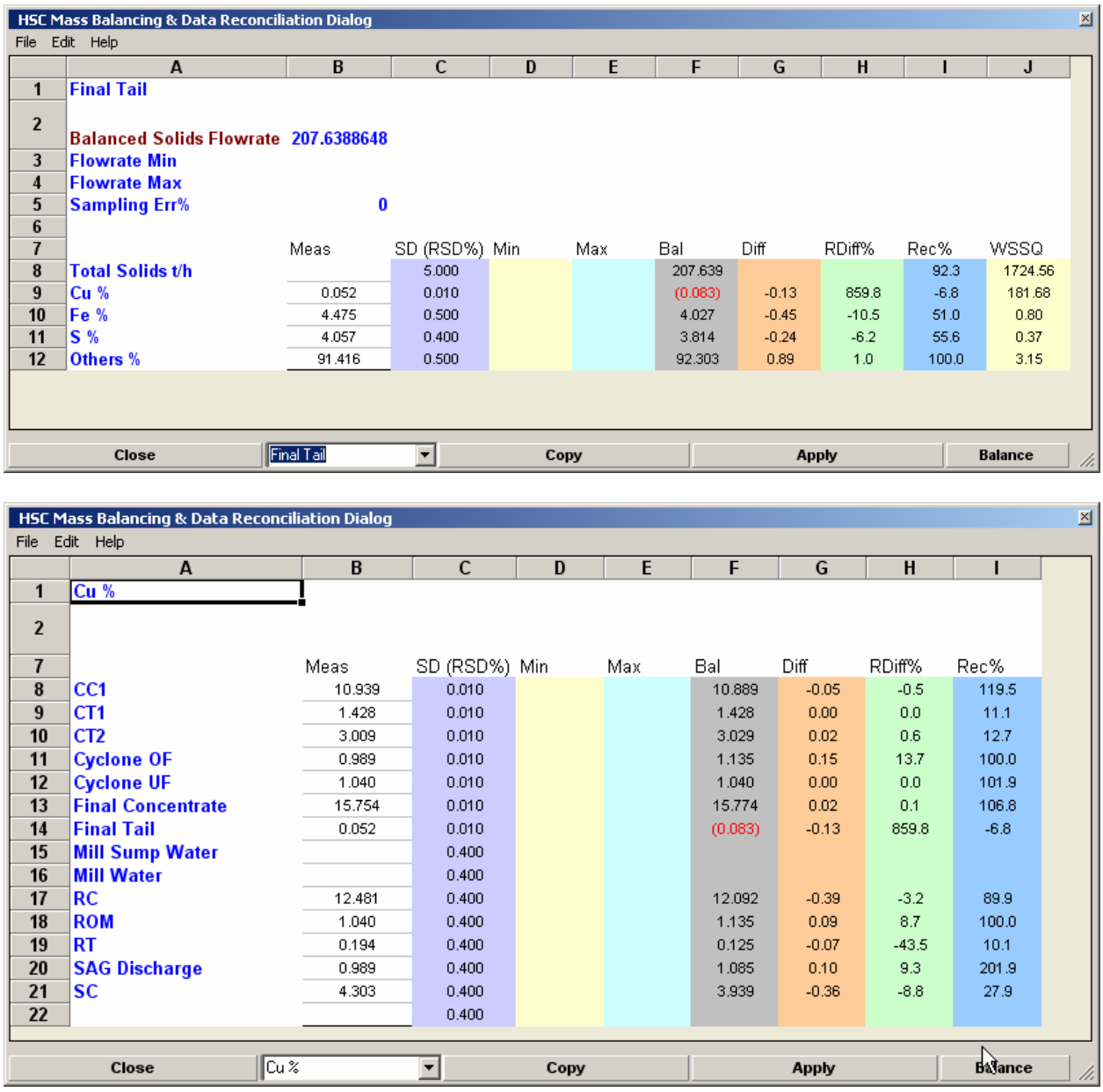

HSC Mass Balancing & Data Reconciliation Dialog
File Edit Help
Final Tail
Balanced Solids Flowrate 207.6388648
Flowrate Min
Flowrate Max
Sampling Err% 0
Meas SD (RSD%) Min Max Bal Diff RDiff% Rec% WSSQ
Total Solids t/h 5.000 207.639 92.3 1724.56
Cu % 0.052 0.010 (0.083) -0.13 859.8 -6.8 181.68
Fe % 4.475 0.500 4.027 -0.45 -10.5 51.0 0.80
S % 4.057 0.400 3.814 -0.24 -6.2 55.6 0.37
Others % 91.416 0.500 92.303 0.89 1.0 100.0 3.15
Close Final Tail Copy Apply Balance
HSC Mass Balancing & Data Reconciliation Dialog
File Edit Help
Cu %
Meas SD (RSD%) Min Max Bal Diff RDiff% Rec%
CC1 10.939 0.010 10.889 -0.05 -0.5 119.5
CT1 1.428 0.010 1.428 0.00 0.0 11.1
CT2 3.009 0.010 3.029 0.02 0.6 12.7
Cyclone OF 0.989 0.010 1.135 0.15 13.7 100.0
Cyclone UF 1.040 0.010 1.040 0.00 0.0 101.9
Final Concentrate 15.754 0.010 15.774 0.02 0.1 106.8
Final Tail 0.052 0.010 (0.083) -0.13 859.8 -6.8
Mill Sump Water 0.400
Mill Water 0.400
RC 12.481 0.400 12.092 -0.39 -3.2 89.9
ROM 1.040 0.400 1.135 0.09 8.7 100.0
RT 0.194 0.400 0.125 -0.07 -43.5 10.1
SAG Discharge 0.989 0.400 1.085 0.10 9.3 201.9
SC 4.303 0.400 3.939 -0.36 -8.8 27.9
0.400
Close Cu % Copy Apply Balance

Figure 22. HSC Mass Balance & Data Reconciliation Dialog. Above = Stream view; Below = Element View.

48.7. Reporting Tools

HSC Sim has a number of reporting tools to study, evaluate, fine-tune and finally report the mass balance solution.

48.7.1. Parity Difference and Other Charts

To evaluate the mass balance in the Parity Chart, i.e. in an XY diagram where measured is plotted against balanced, select from the menu Graphics – Parity Chart (Figure 23). You will see a plot of the first component. Change the component from the "Field" combo-box (Figure 24).

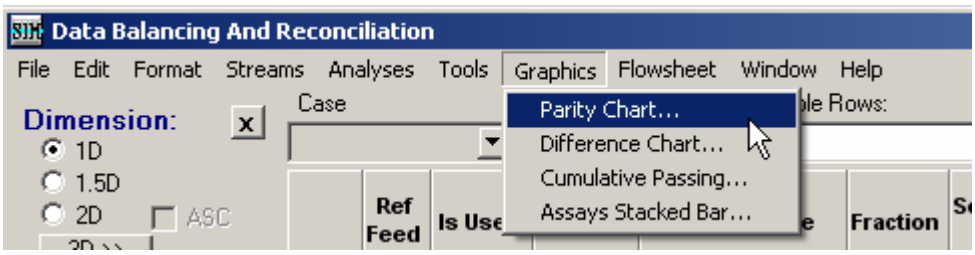


Figure 23. Drawing a parity chart.

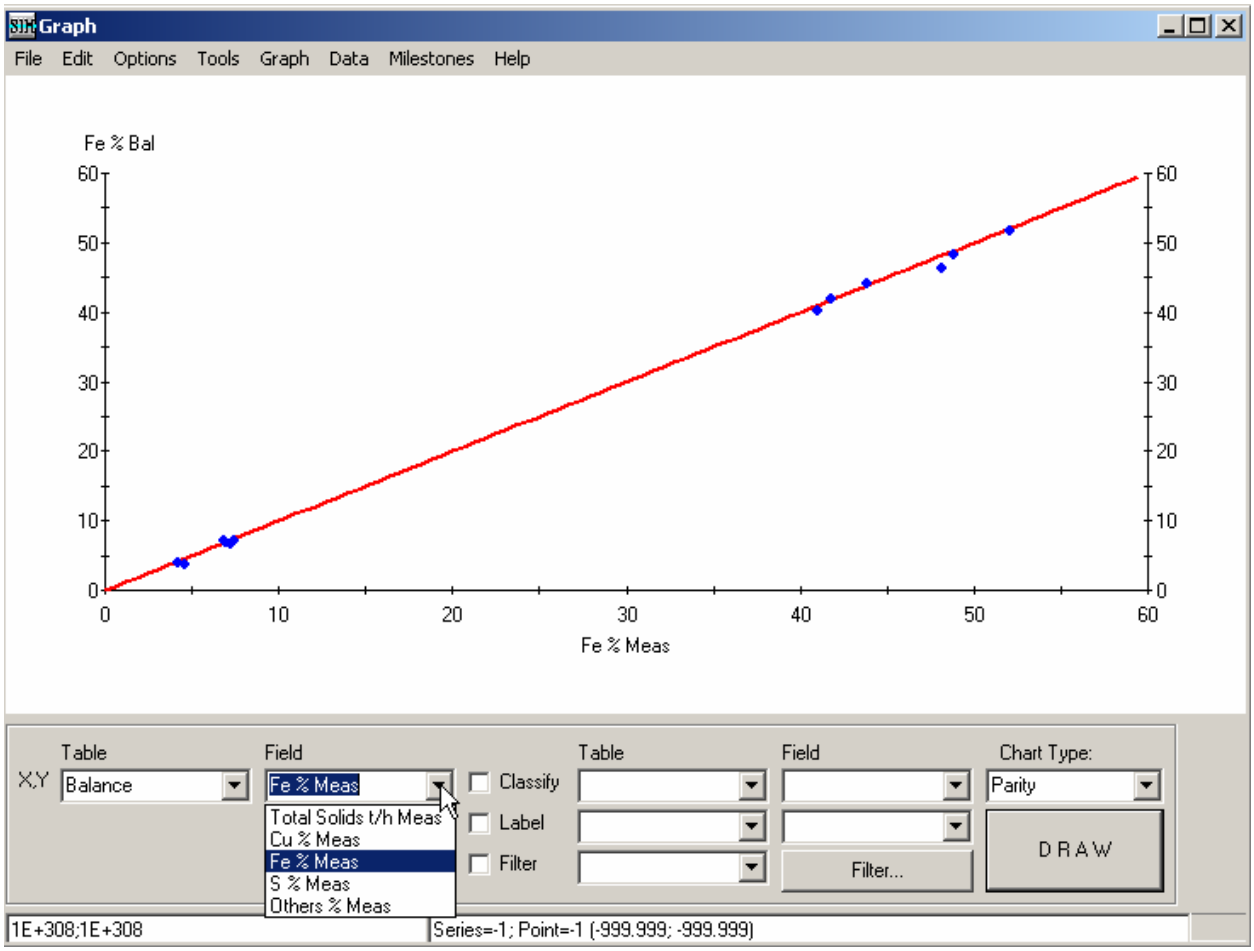


Figure 24. Parity Chart.

The difference chart plots the absolute (or relative) difference against the measured value (Figure 25). A cumulative passing chart can be drawn only if the case is 1.5D (see examples in manual “49 Mass Balancing Examples”.

The “Assays Stacked Bar” chart is useful especially when solving the problem where the constraint “Component Sum = 100” is used (Figure 26).

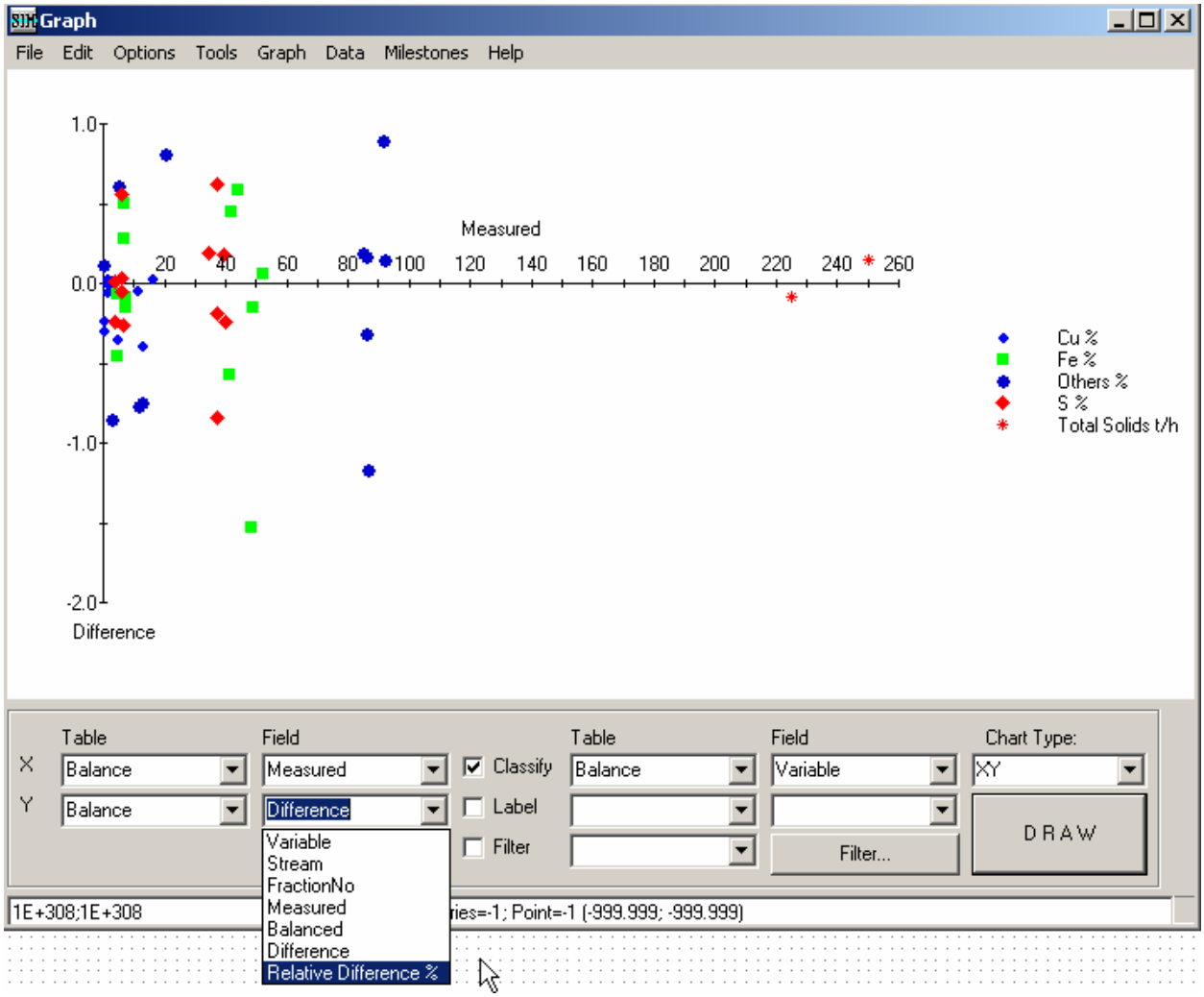


Figure 25. Difference chart. You can change from an absolute difference to a relative difference in the "Y Field" combo-box.

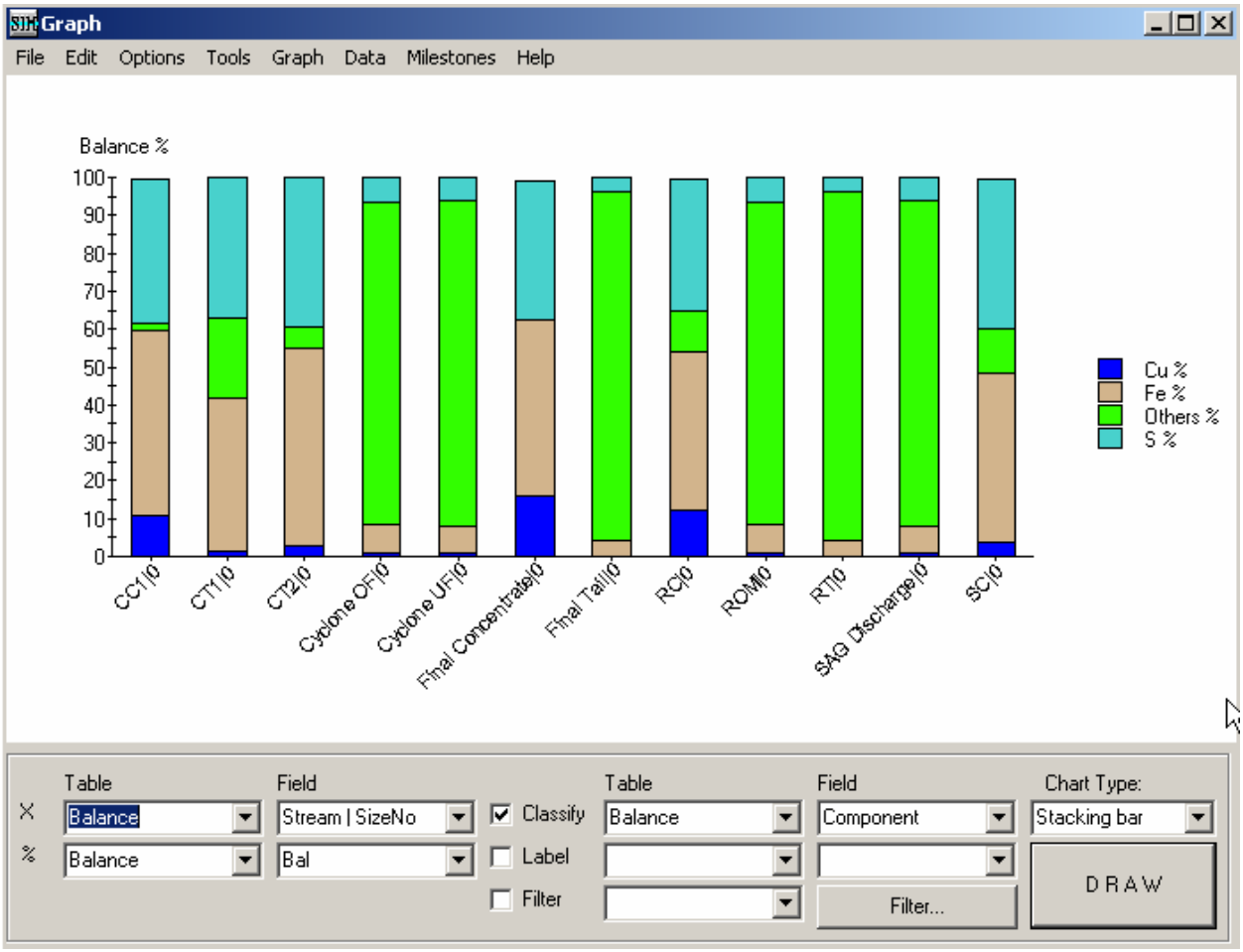


Figure 26. Assays Stacked Bar chart.

48.7.2. Report

Pressing the **7**. **Report** button in the navigator will make the Report spreadsheet visible (Figure 27). The report consists of four pages:
1) Goodness shows the goodness of the mass balance (Figure 28),
2) Node Balance reports the balance by mass balance node (Figure 29),
3) Stream Summary reports the streams horizontally (Figure 30)
4) StreamsV reports the streams vertically (Figure 31).

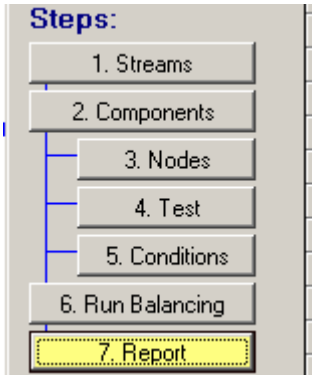


*Figure 27. Press **Report** to make the Report Spreadsheet visible.*

< Back | Copy | Visualize.. | Tables..

Goodness | Node Balance | StreamSummary | StreamsV

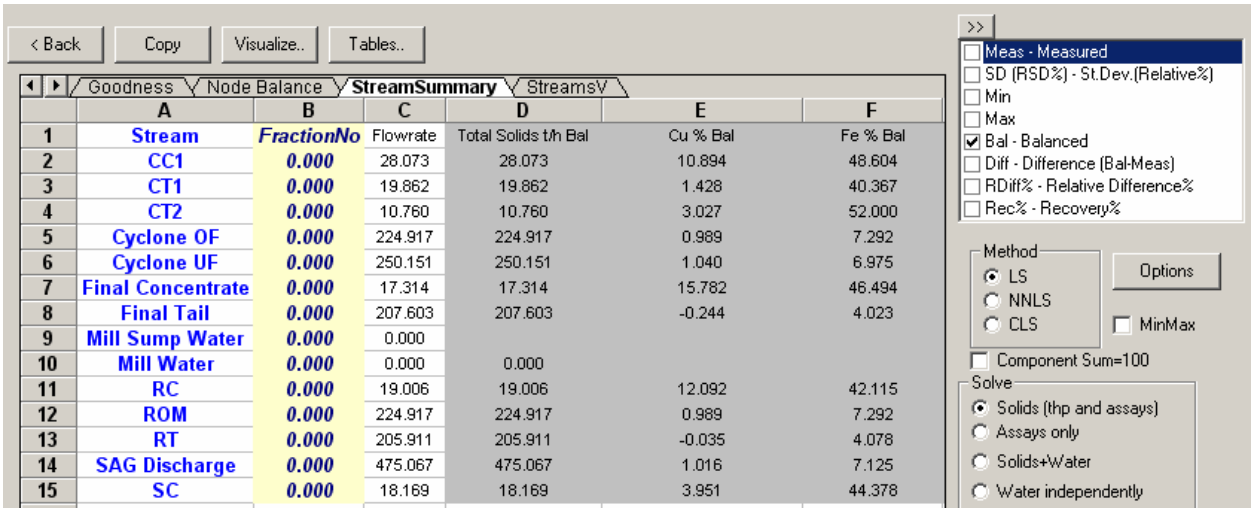
	A	B	C	D	E	F	G
1	Component	WSSQ	DiffTot	RelDiff	AVG_SD	AVG_RSD	N
2	Total Solids t/h	0.001	0.317	0.045	5.000	2.143	3.000
3	Cu %	34.335	1.437	2.822	0.255	5.860	12.000
4	Fe %	2.867	4.889	1.573	1.446	5.565	12.000
5	S %	3.331	3.429	1.329	0.950	4.412	12.000
6	Others %	32.776	6.794	1.176	0.433	0.897	12.000
7	Sum	73.311	16.866	6.945	8.084	18.877	51.000
8	Avg	6.109	1.406	0.579	0.674	1.573	4.250
9							
10	Stream	Sum WSSQ	DiffSum	RelDiffSum	RelDiffAvg	N	
11	CC1	32.774	1.671	35.436	7.087	4.000	
12	CT1	2.728	1.572	5.866	1.173	4.000	
13	CT2	6.279	0.929	13.147	2.629	4.000	
14	Cyclone OF	0.626	0.630	5.619	1.124	5.000	
15	Cyclone UF	0.211	0.498	2.875	0.575	5.000	
16	Final Concentrate	10.118	2.512	205.683	41.137	4.000	
17	Final Tail	4.506	1.893	325.282	65.056	4.000	
18	Mill Sump Water					0.000	
19	Mill Water					0.000	
20	RC	3.342	1.802	11.654	2.331	4.000	
21	ROM	8.464	2.367	22.728	4.546	5.000	
22	RT	0.432	0.445	291.318	58.264	4.000	
23	SAG Discharge	0.764	0.688	8.061	1.612	4.000	
24	SC	3.066	1.861	16.416	3.283	4.000	
25	Total	73.311	16.866				

Figure 28. The first page of the Report shows the "goodness" of the mass balancing.

Goodness | Node Balance | StreamSummary | StreamsV

	A	B	C	D	E	F	G	H	I	J	K	L
1	Node	Units	Equations	Stream	Mass%	Total Solids t/h	Cu %	Fe %	S %	Others %	Total Solids t/h Rec%	Cu % Rec%
2	Node 1 (Fr	SAG + Pro	ROM + Cyclone UF = SAG Discharge									
3			Inputs	ROM	224.917	224.917	0.989	7.292	6.338	85.216	100.000	100.000
4				Cyclone UF	250.151	250.151	1.040	6.975	5.952	86.076	111.219	116.942
5				Total Input	475.067	475.067	1.016	7.125	6.135	85.669	211.219	216.942
6			Outputs	SAG Discharge	475.067	475.067	1.016	7.125	6.135	85.669	211.219	216.942
7				Total Output	475.067	475.067	1.016	7.125	6.135	85.669	211.219	216.942
8			Balance		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
9												
10	Node 2 (Fr	1st Cleane	CT2 + RC + SC = CC1 + CT1									
11			Inputs	CT2	10.760	10.760	3.027	52.000	39.988	5.435	4.784	14.637
12				RC	19.006	19.006	12.092	42.115	34.493	10.794	8.450	103.282
13				SC	18.169	18.169	3.951	44.378	39.528	11.814	8.078	32.262
14				Total Input	47.935	47.935	6.971	45.191	37.635	9.978	21.312	150.181
15			Outputs	CC1	28.073	28.073	10.894	48.604	37.927	2.154	12.482	137.437
16				CT1	19.862	19.862	1.428	40.367	37.223	21.036	8.831	12.744
17				Total Output	47.935	47.935	6.971	45.191	37.635	9.978	21.312	150.181
18			Balance		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19												

Figure 29. Page two of the Report.



	A	B	C	D	E	F
1	Stream	FractionNo	Flowrate	Total Solids t/h Bal	Cu % Bal	Fe % Bal
2	CC1	0.000	28.073	28.073	10.894	48.604
3	CT1	0.000	19.862	19.862	1.428	40.367
4	CT2	0.000	10.760	10.760	3.027	52.000
5	Cyclone OF	0.000	224.917	224.917	0.989	7.292
6	Cyclone UF	0.000	250.151	250.151	1.040	6.975
7	Final Concentrate	0.000	17.314	17.314	15.782	46.494
8	Final Tail	0.000	207.603	207.603	-0.244	4.023
9	Mill Sump Water	0.000	0.000			
10	Mill Water	0.000	0.000	0.000		
11	RC	0.000	19.006	19.006	12.092	42.115
12	ROM	0.000	224.917	224.917	0.989	7.292
13	RT	0.000	205.911	205.911	-0.035	4.078
14	SAG Discharge	0.000	475.067	475.067	1.016	7.125
15	SC	0.000	18.169	18.169	3.951	44.378

Figure 30. Report, page three. Currently only balanced values (Bal) are selected to be reported.

Goodness | Node Balance | StreamSummary | StreamsV

	A	B	C	D	E	F
1	Stream	CC1	CT1	CT2	Cyclone OF	Cyclone UF
2	FractionNo	0.000	0.000	0.000	0.000	0.000
3	Flowrate	28.07332274	19.86178809	10.75962009	224.9167214	250.1505081
4	Total Solids t/h Meas				225.000	250.000
5	Total Solids t/h SD (RSD%)	5.000	5.000	5.000	5.000	5.000
6	Total Solids t/h Bal	28.073	19.862	10.760	224.917	250.151
7	Total Solids t/h Diff				-0.08	0.15
8	Total Solids t/h RDiff%				0.0	0.1
9	Total Solids t/h Rec%	12.5	8.8	4.8	100.0	111.2
10	Cu % Meas	10.939	1.428	3.009	0.989	1.040
11	Cu % SD (RSD%)	0.010	0.010	0.010	0.010	0.010
12	Cu % Bal	10.894	1.428	3.027	0.989	1.040
13	Cu % Diff	-0.05	0.00	0.02	0.00	0.00
14	Cu % RDiff%	-0.4	0.0	0.6	0.0	0.0
15	Cu % Rec%	137.4	12.7	14.6	100.0	116.9
16	Fe % Meas	48.752	40.933	51.936	7.380	7.127
17	Fe % SD (RSD%)	2.538	2.147	2.697	0.500	0.500
18	Fe % Bal	48.604	40.367	52.000	7.292	6.975
19	Fe % Diff	-0.15	-0.57	0.06	-0.09	-0.15
20	Fe % RDiff%	-0.3	-1.4	0.1	-1.2	-2.2
21	Fe % Rec%	83.2	48.9	34.1	100.0	106.4
22	S % Meas	37.302	37.417	40.227	6.606	5.925

Figure 31. Report, page four. Items to be reported are selected from the Balance/Report options (see previous figure where only the balanced values are selected, here Meas, Bal, Dif, RDiff% and Rec% are selected to be visible).

48.7.3. Visualizing on the flowsheet

A balance result can also be visualized on the flowsheet. To display any component and any item (measured, balanced, standard deviation, minimum, maximum, difference, relative difference, recovery) select the corresponding column on the Data Sheet and the Mass Balance window will be minimized and the flowsheet will be shown displaying the selected item in a Sankey diagram (Figure 32). To get back to the Balance window use the Balance button (Figure 33).

To visualize the “goodness” values from the report, please press **Visualize** in the Report and select between Sum WSSQ (sum of weighted least squared), DiffSum (sum of total differences) and RelDiffSum (sum of relative differences) (Figure 34). These figures will help in finding the streams with the biggest adjustments and to fine-tune the mass balancing (Figure 35).

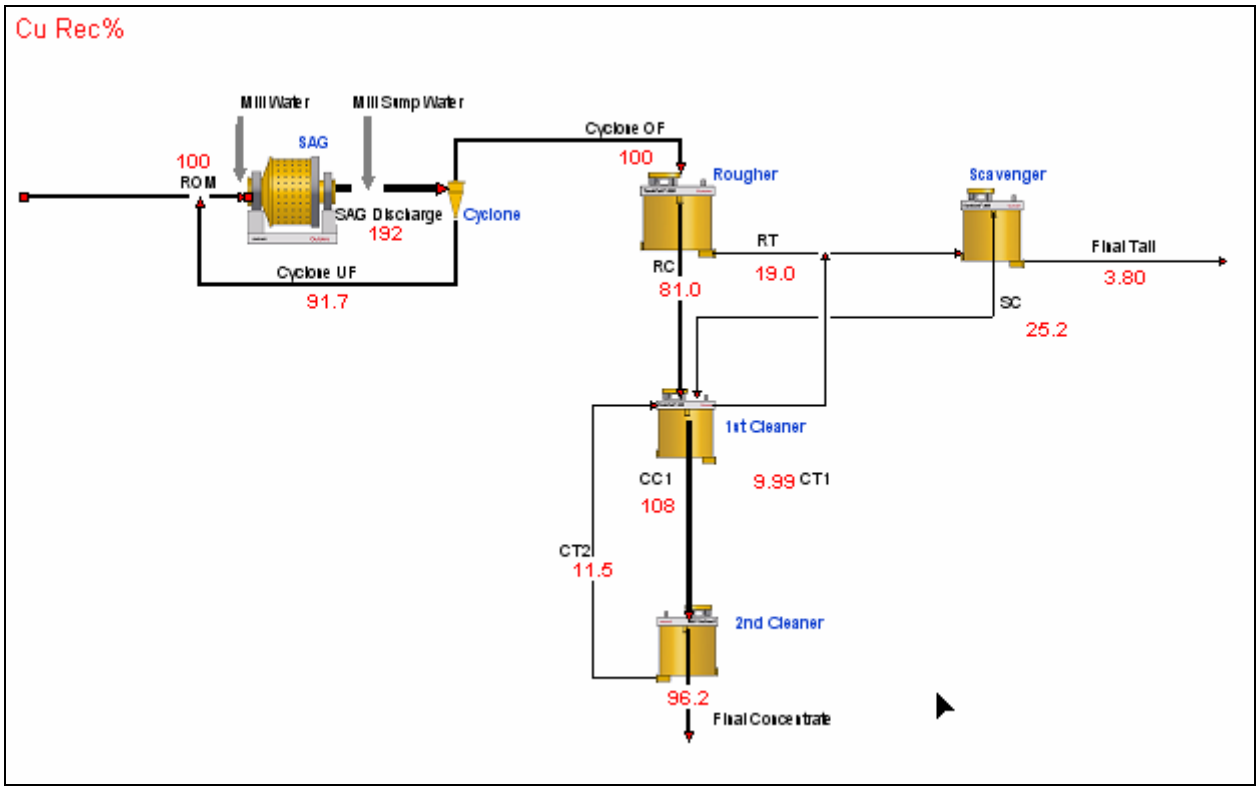


Figure 32. Mass balance result, copper recovery, displayed as a Sankey diagram.

Figure 33. Press Balance >> button to get back to the Balance window.

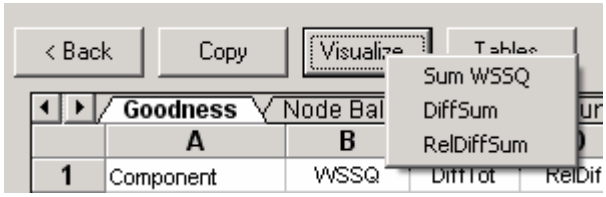


Figure 34. Visualizing the ”goodness” values.

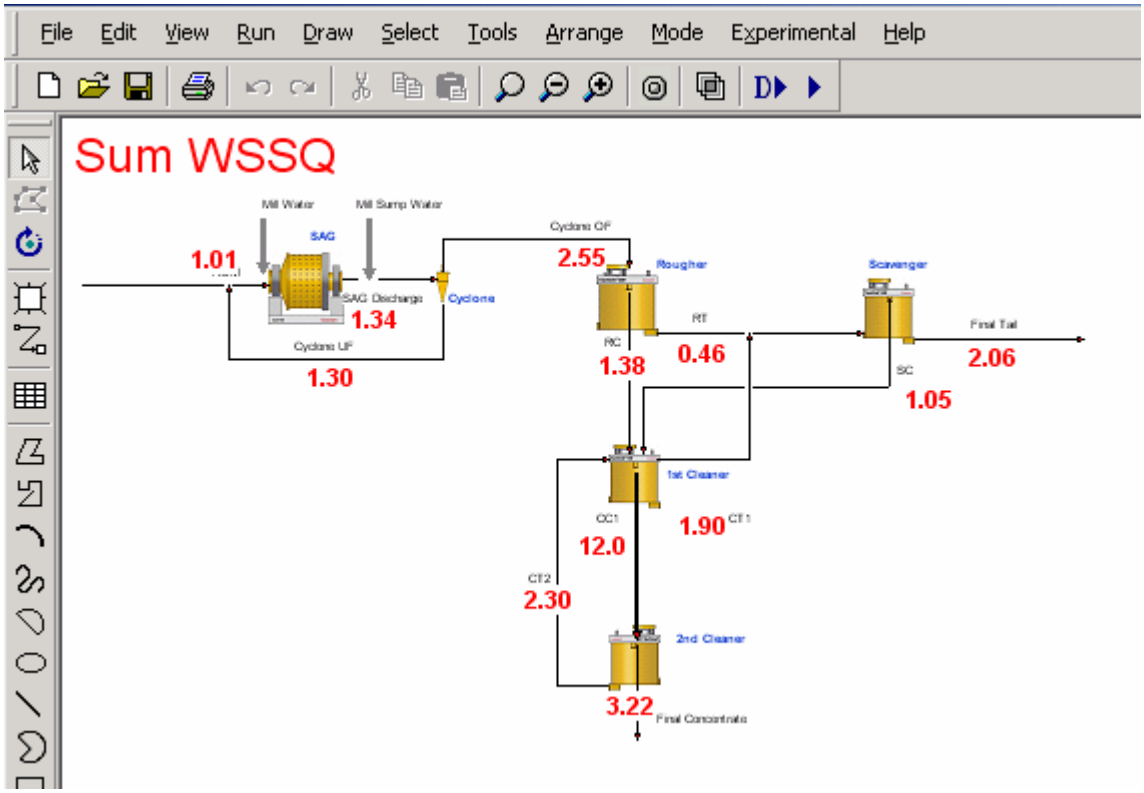


Figure 35. Visualizing Sum of weighted least squares. The biggest adjustments (considering the standard deviation) have been made in the stream CC1 (12.0).

To visualize the mass balancing result as stream tables select in the menu: Flowsheet – Create Stream Tables (Figure 36). Select the components and items (Figure 37) and HSC Sim will create stream tables next to the streams (Figure 38). The tables are placed in the Balance layer. Reorganize the tables and use Copy – Paste or Print to report the result out.

If you rebalance, regenerate the balance tables by selecting Flowsheet – Update Stream Tables. If you want to freeze the mass balance result in the stream tables (i.e. the values would not change even though the Update Stream Tables were selected) select Flowsheet – Move Tables into Layer and Inactivate. Select the layer, give the layer a name and HSC Sim will move the balance tables into the selected layer. If you create new Stream Tables they will appear in the Balance layer. If continuing the loop Create and Move you can report different mass balancing conditions, and cases, on one flowsheet. Each balance is located in its own layer.

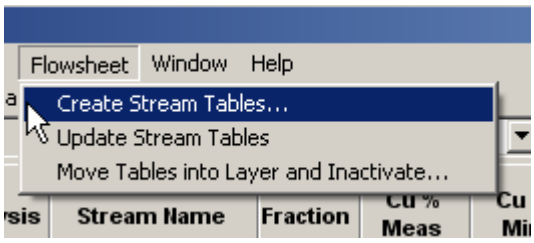


Figure 36. Creating stream tables.

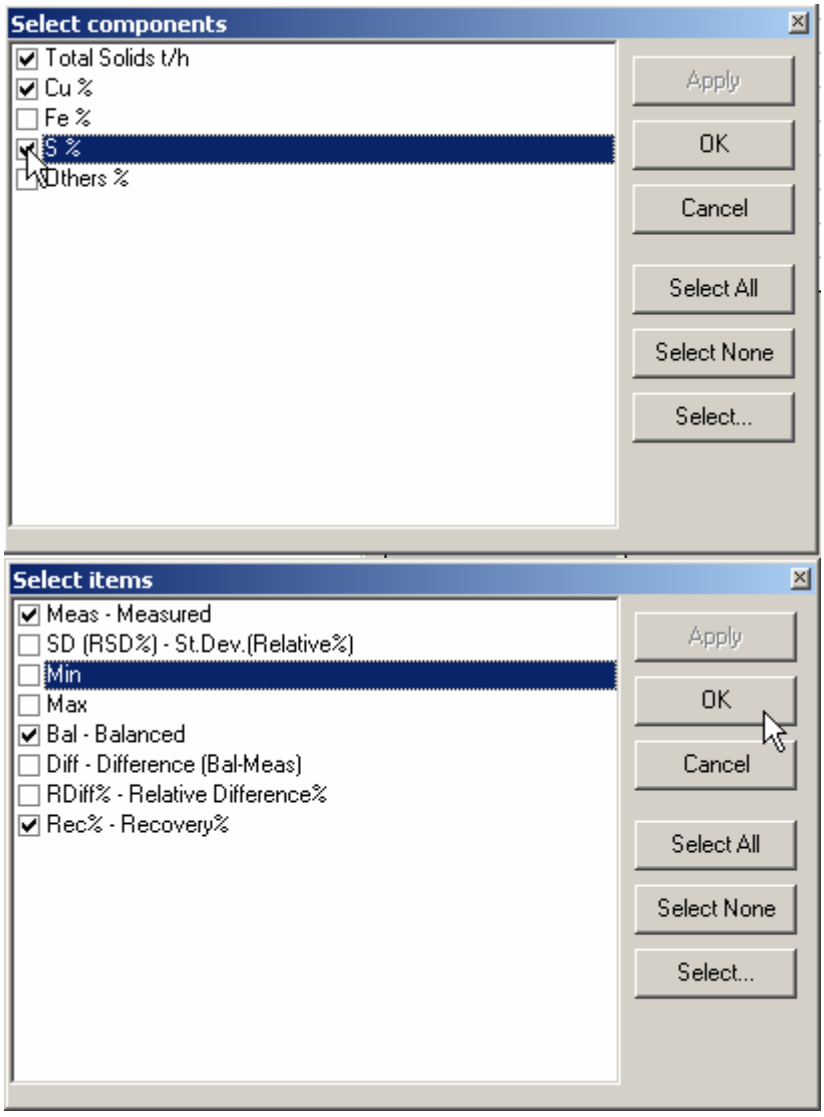


Figure 37. Select the components (above) and items (below).

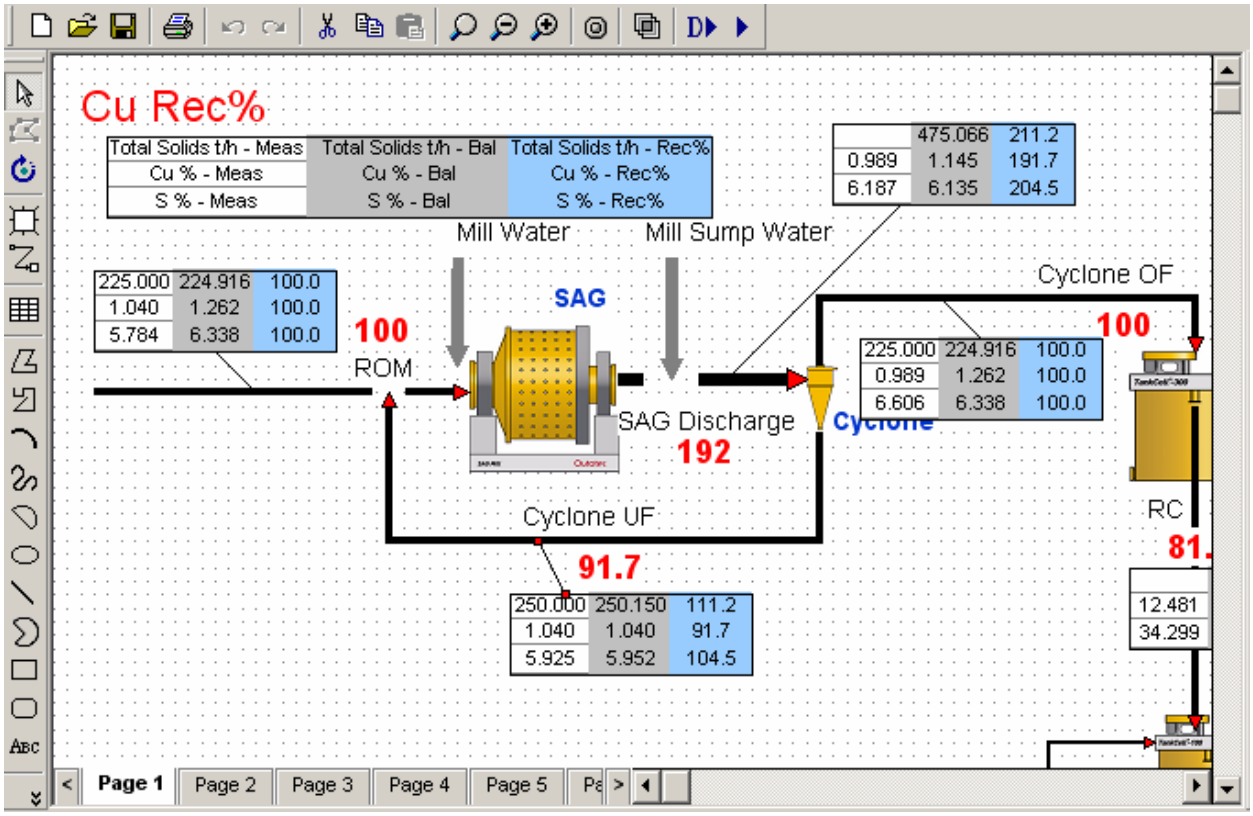


Figure 38. Mass balance result reported as stream tables on the flowsheet.

48.8. Saving Mass Balance

48.8.1. Balance file

Each time you exit the mass balance window, HSC Sim will save the Balance.xls file in the very same folder where the flowsheet file exists. The Balance.xls file consists of the following pages (Figure 39):

- Data = original data used in mass balancing
- CV = error model and standard deviations
- Units = list of units and check for 2D mass balance (see the manual "49 Sim Mass Balance Examples.xls")
- Conditions = mass balance method
- Balance = the Data Sheet

If you want to restore the last Balance.xls file, please select File – Restore last (Figure 40).

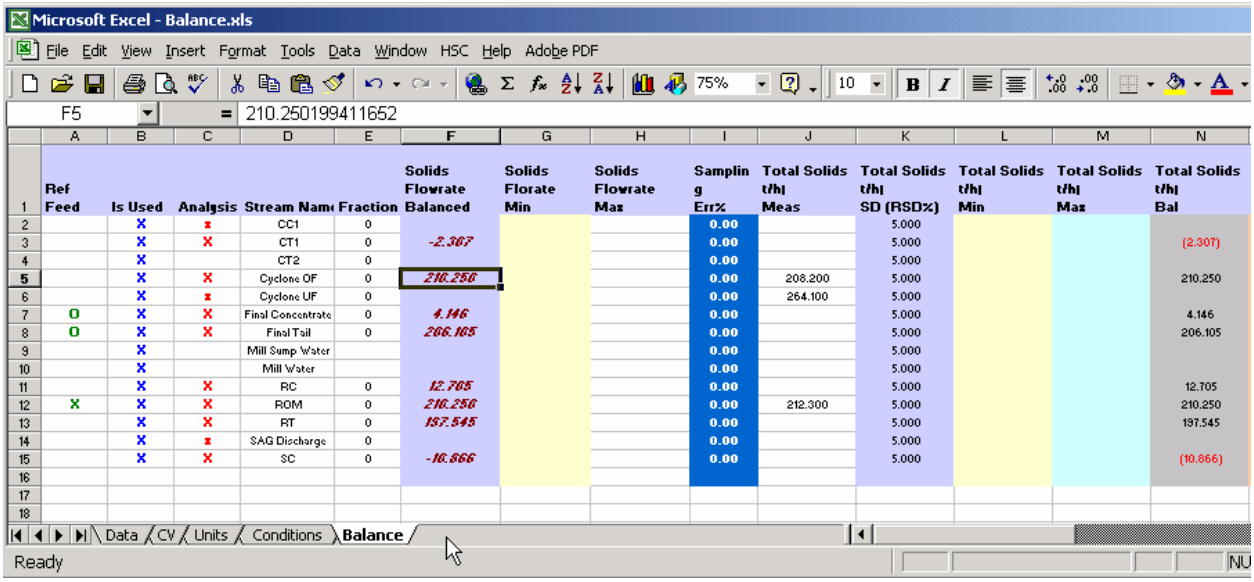


Figure 39. Balance.xls file.

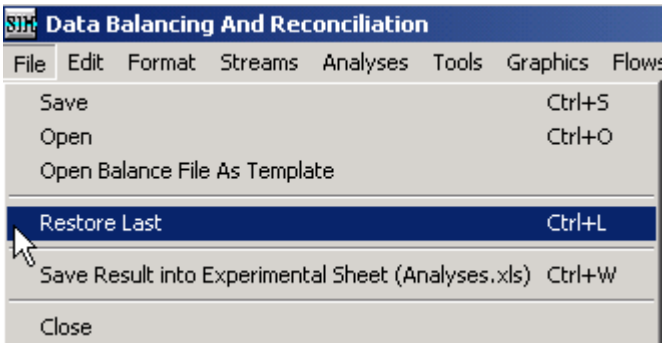

Data Balancing And Reconciliation
File Edit Format Streams Analyses Tools Graphics Flows
Save Ctrl+S
Open Ctrl+O
Open Balance File As Template
Restore Last Ctrl+L
Save Result into Experimental Sheet (Analyses.xls) Ctrl+W
Close

Figure 40. Restoring the last Balance file.

48.8.2. Save

Selecting File – Save will let you save the Balance file with a different name. The default name is HSCBalance_year_month_day_hours_minutes.xls (Figure 41). The structure of the file is similar to the Balance.xls file (see above, Figure 39).

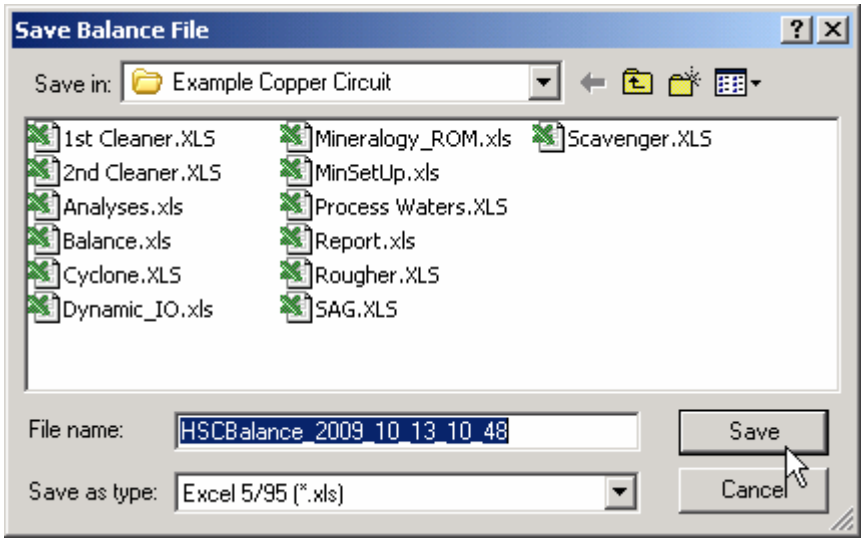


Figure 41. Saving Balance file with different name.

48.8.3. Saving the result into Assays.xls

From the menu, select File – Save Result into Experimental Sheet (Analyses.xls) (Figure 42). Give the sheet a name (Figure 43) and HSC Sim will copy the balanced values into the sheet, and fill in the Source and Destination and calculate recoveries (Figure 44).

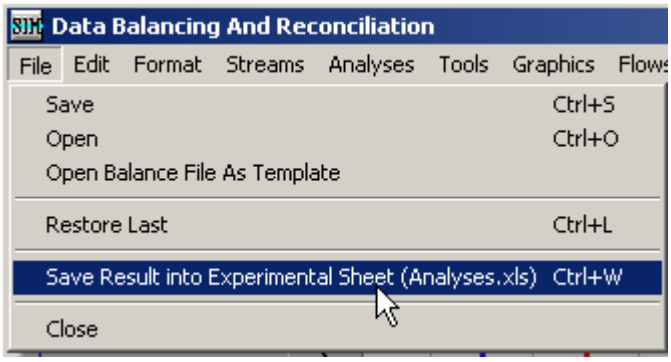

Data Balancing And Reconciliation
File Edit Format Streams Analyses Tools Graphics Flows
Save Ctrl+S
Open Ctrl+O
Open Balance File As Template
Restore Last Ctrl+L
Save Result into Experimental Sheet (Analyses.xls) Ctrl+W
Close

Figure 42. Saving result into Analyses.xls.

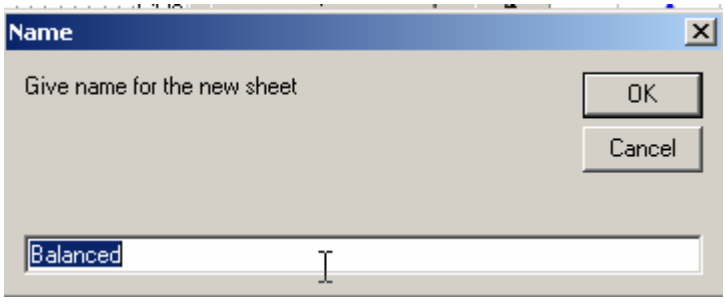


Figure 43. Give the sheet a name.

Experimental Data

File Edit Tools Data Graphics Model Create Format Window Help

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Stream	Source	Destination	Mass%	FractionNo	Total Solids t/h	Cu %	Fe %	S %	Others %	Cu Rec%	Fe Rec%	S Rec%	Others Rec%
2	CC1	1st Cleaner	2nd Cleaner	28.1	0	28.1	10.885	48.6	37.9	2.154	107.7	83.2	74.7	0.3155
3	CT1	1st Cleaner	Scavenger	19.9	0	19.9	1.428	40.4	37.2	21.036	10.0	48.9	51.9	2.1799
4	CT2	2nd Cleaner	1st Cleaner	10.8	0	10.8	3.030	52.0	40.0	5.435	11.5	34.1	30.2	0.3051
5	Cyclone OF	Cyclone	Rougher	224.9	0	224.9	1.262	7.3	6.3	85.216	100.0	100.0	100.0	100.0000
6	Cyclone UF	Cyclone	SAG	250.1	0	250.1	1.040	7.0	6.0	86.076	91.7	106.4	104.5	112.3421
7	Final Concentrate	2nd Cleaner	?	17.3	0	17.3	15.767	46.5	36.6	0.115	96.2	49.1	44.5	0.0104
8	Final Tail	Scavenger	?	207.6	0	207.6	0.052	4.0	3.8	92.313	3.8	50.9	55.5	99.9896
9	Mill Sump Water	Process Waters	Cyclone											
10	Mill Water	Process Waters	SAG											
11	RC	Rougher	1st Cleaner	19.0	0	19.0	12.097	42.1	34.5	10.794	81.0	48.8	46.0	1.0704
12	ROM	?	SAG	224.9	0	224.9	1.262	7.3	6.3	85.216	100.0	100.0	100.0	100.0000
13	RT	Rougher	Scavenger	205.9	0	205.9	0.261	4.1	3.7	92.085	19.0	51.2	54.0	98.9296
14	SAG Discharge	SAG	Cyclone	475.1	0	475.1	1.145	7.1	6.1	85.669	191.7	206.4	204.5	212.3421
15	SC	Scavenger	1st Cleaner	18.2	0	18.2	3.930	44.4	39.5	11.814	25.2	49.2	50.4	1.1199
16														
17														

Figure 44. Balance result (Balanced values only) in the Experimental Data (Analyses.xls) as a new sheet.

48.8.4. Opening mass balance file as an template

You can open previously saved mass balance files as templates by selecting File – Open Balance File As Template (Figure 45). HSC will now take the stream selections, error models, min-max values from the template and then use the measured values of the current data. To use this the template data and current mass balance problem should be similar in structure; i.e. the same components assayed in the same streams.

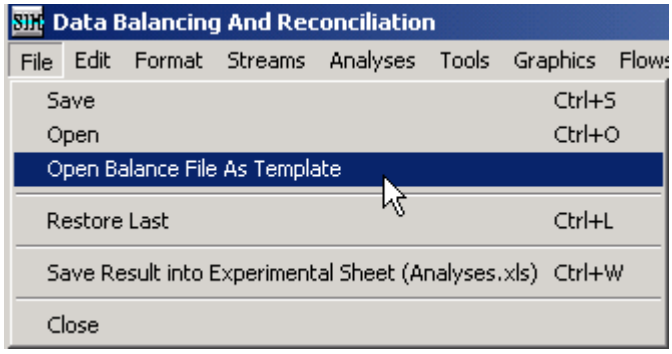

Data Balancing And Reconciliation
File Edit Format Streams Analyses Tools Graphics Flows
Save Ctrl+S
Open Ctrl+O
Open Balance File As Template
Restore Last Ctrl+L
Save Result into Experimental Sheet (Analyses.xls) Ctrl+W
Close

Figure 45. Opening mass balance file as an template.

48.9. Solving Several Cases

With HSC Sim it is possible to solve huge number of similar mass balance cases easily in one go. This kind of feature is needed when mass balancing e.g. shift or day assays from a long period, say a year. The procedure is as follows:

- In the Assays have as a first column the "Case." Organize so that each case has the same streams listed. Bring in your assays for each case (Figure 46).
- Press the Mass Balancing and Data Reconciliation button
- Do the Mass Balance Wizard steps as explained in chapter 48.5
- From the Case combo-box select the case you want to work with first (Figure 47).
- Define the mass balancing conditions, probably it would be safer to use NNLS than the LS method
- Solve the mass balance for the first case and evaluate the result

- Fine-tune if needed and finally when you are happy with the result you may change the case to some other and repeat the balance and fine-tuning
- Finally, when studying enough different cases you can select from the menu Tools – Solve All Cases (Figure 48).
- Give a name for the new sheet to be placed in Analyses.xls file (Figure 49).
- HSC Sim will solve all the cases one by one and report them to the Analyses.xls file on the sheet you just named before.
- After finding a solution for all cases, HSC will make Experimental Data visible. You can complete the mass balance by selecting "Identify Streams" and Tools – Calculate Recoveries (Figure 50).

Experimental Data

File Edit Tools Data Graphics Model Create Format Window Help

	A	B	C	D	E	F
1	Set	Stream	Source	Destination	Solids Re	Total Soli F
2	1	ROM	?	SAG		225
3	1	SAG Discharge	SAG	Cyclone		
4	1	Cyclone UF	Cyclone	SAG		250
5	1	Cyclone OF	Cyclone	Rougher		225
6	1	RC	Rougher	1st Cleaner		
7	1	CC1	1st Cleaner	2nd Cleaner		
8	1	Final Concentrate	2nd Cleaner	?		
9	1	RT	Rougher	Scavenger		
10	1	SC	Scavenger	1st Cleaner		
11	1	Final Tail	Scavenger	?		
12	1	CT2	2nd Cleaner	1st Cleaner		
13	1	CT1	1st Cleaner	Scavenger		
14	2	ROM	?	SAG		212.3
15	2	SAG Discharge	SAG	Cyclone		
16	2	Cyclone UF	Cyclone	SAG		264.1
17	2	Cyclone OF	Cyclone	Rougher		208.2
18	2	RC	Rougher	1st Cleaner		
19	2	CC1	1st Cleaner	2nd Cleaner		
20	2	Final Concentrate	2nd Cleaner	?		
21	2	RT	Rougher	Scavenger		
22	2	SC	Scavenger	1st Cleaner		

Figure 46. Organizing analyses when you have several similar mass balancing cases to be solved. The first column is called "Set"(also Case can be used) and the streams are listed horizontally.

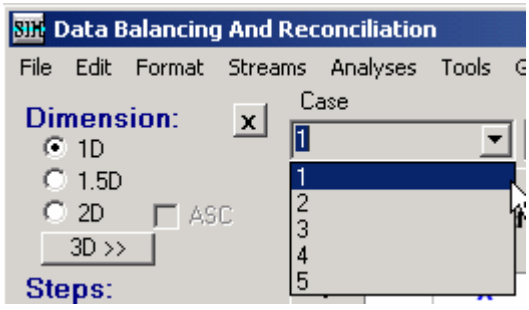


Figure 47. Changing a Case (= Set).

Figure 48. Solving all mass balance cases.

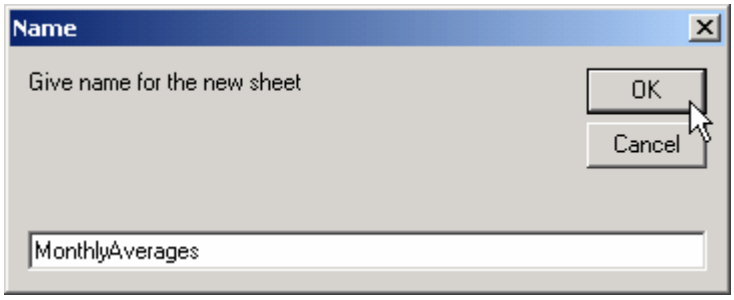


Figure 49. Give the sheet name (in Analyses.xls) where the results are stored.

Experimental Data

File Edit Tools Data Graphics Model Create Format Window Help

	A	B	C	D	E	F	G	H	I	J
1	Set	Stream	Source	Destination	Mass%	FractionNo	Total Solids t/h	Cu %	Fe %	S %
2	1	CC1	1st Cleaner	2nd Cleaner	0.000		0.000	0.000	0.0	0.0
3	1	CT1	1st Cleaner	Scavenger	24.648		24.648	1.535	40.4	37.2
4	1	CT2	2nd Cleaner	1st Cleaner	0.000		0.000	0.000	0.0	0.0
5	1	Cyclone OF	Cyclone	Rougher	224.999		224.999	1.149	7.4	6.3
6	1	Cyclone UF	Cyclone	SAG	0.000		0.000	0.000	0.0	0.0
7	1	Final Concentrate	2nd Cleaner	?	16.818		16.818	16.160	47.6	37.3
8	1	Final Tail	Scavenger	?	208.181		208.181	-0.063	4.1	3.8
9	1	Mill Sump Water	Process Waters	Cyclone	0.000		0.000	0.000	0.0	0.0
10	1	Mill Water	Process Waters	SAG	0.000		0.000	0.000	0.0	0.0
11	1	RC	Rougher	1st Cleaner	18.563		18.563	11.788	42.1	34.5
12	1	ROM	?	SAG	224.999		224.999	1.149	7.4	6.3
13	1	RT	Rougher	Scavenger	206.436		206.436	0.193	4.2	3.8
14	1	SAG Discharge	SAG	Cyclone	0.000		0.000	0.000	0.0	0.0
15	1	SC	Scavenger	1st Cleaner	22.903		22.903	3.964	44.3	39.5
16	2	CC1	1st Cleaner	2nd Cleaner	0.000		0.000	0.000	0.0	0.0
17	2	CT1	1st Cleaner	Scavenger	0.000		0.000	1.400	40.9	37.4
18	2	CT2	2nd Cleaner	1st Cleaner	0.000		0.000	0.000	0.0	0.0

Figure 50. Data

48.10. Solving 2D cases

When you have a 2D (size by size assay data) the procedure in HSC Sim is:

1. Organize your data in Analyses.xls in a way that, for the unsized data, the FractionNo is zero (FractionNo = 0) and the size fractions follow with numbers 1,2,3 ….. Give the “Fraction name” and Fraction mass percentage (Fraction m%) (Figure 51). To initialize select from the menu “Create – Stream Properties Sheet – Horizontal With Multiple Size Fractions” (Figure 52).
2. Solve first the 1D case
3. Change the dimensions to 2D, 1D result is now frozen (Figure 53)
4. Check the conditions and run the mass balance for 2D
5. Study the result, report and save. The file will have two balance pages: 1D and 2D (Figure 54).

Please note that when changing from 1D to 2D, the 1D mass balance is frozen, i.e. it will not be changed. 2D data does not need to be complete: some streams mass balanced in 1D may be missing analyses and some components may be missing in 2D data.

For more information, see the "49 Sim Mass Balance Examples.doc" manual and the 2D cases there.

File Edit Tools Data Graphics Model Create Format Window Help

	A	B	C	D	E	F	G
1	Stream	Source	Destinatio	Solids Re	FractionN	Fraction r	Fraction m%
2	ROM	?	SAG		0	Bulk	
3	ROM	?	SAG		1	0-20 um	1.1
4	ROM	?	SAG		2	20-37 um	1.7
5	ROM	?	SAG		3	37-74 um	4.5
6	ROM	?	SAG		4	74-106 um	12
7	ROM	?	SAG		5	106-250 um	80.7
8	SAG Discharge	SAG	Cyclone		0	Bulk	
9	SAG Discharge	SAG	Cyclone		1	0-20 um	13.7
10	SAG Discharge	SAG	Cyclone		2	20-37 um	9.6
11	SAG Discharge	SAG	Cyclone		3	37-74 um	16.6
12	SAG Discharge	SAG	Cyclone		4	74-106 um	9.8
13	SAG Discharge	SAG	Cyclone		5	106-250 um	50.3
14	Cyclone UF	Cyclone	SAG		0	Bulk	
15	Cyclone UF	Cyclone	SAG		1	0-20 um	4.5
16	Cyclone UF	Cyclone	SAG		2	20-37 um	3.2
17	Cyclone UF	Cyclone	SAG		3	37-74 um	10.5
18	Cyclone UF	Cyclone	SAG		4	74-106 um	12.9
19	Cyclone UF	Cyclone	SAG		5	106-250 um	68.9
20	Cyclone OF	Cyclone	Rougher		0	Bulk	

Figure 51. 2D data organized in Experimental Data.

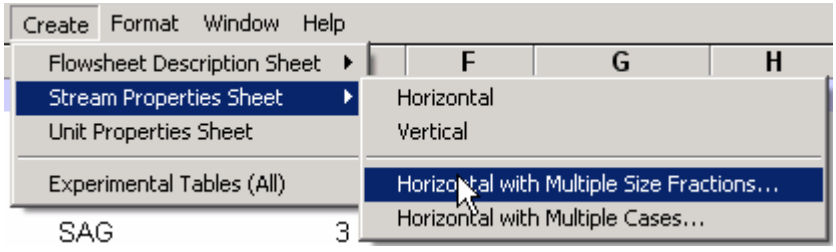


Figure 52. Initializing Stream Properties sheet for multiple size fractions.

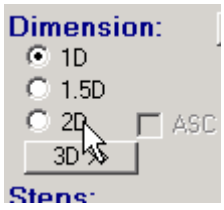


Figure 53. After solving 1D, change to 2D.

2D 1D

	Ref Feed	Is Used	Analysis	Stream Name	Fraction	Solids Flowrate Balanced	Fraction m% Meas	Fraction Bal
1		X	X	CC1	0	9.939	100.000	100.00
2		X	x	CC1	1	3.878	40.000	39.01
3		X	x	CC1	2	2.800	23.700	28.16
4		X	x	CC1	3	2.593	28.400	26.09
5		X	x	CC1	4	0.538	5.700	5.413
6		X	x	CC1	5	0.130	2.200	1.310
7		X	X	CT1	0	6.522	100.000	100.00
8		X	x	CT1	1	2.802	37.200	42.96
9		X	x	CT1	2	1.546	22.300	23.70
10		X	x	CT1	3	1.831	31.600	28.08
11		X	x	CT1	4	0.287	6.700	4.405
12		X	x	CT1	5	0.055	2.200	0.840
13		X	X	CT2	0	3.058	100.000	100.00
14		X	x	CT2	1	1.135	36.500	37.11
15		X	x	CT2	2	0.820	24.500	26.81
16		X	x	CT2	3	0.886	29.500	28.97
17		X	x	CT2	4	0.178	5.400	5.809
18		X	x	CT2	5	0.039	4.100	1.286
19		X	X	Cyclone OF	0	114.869	100.000	100.00
20		X	x	Cyclone OF	1	43.360	39.400	37.74
21		X	x	Cyclone OF	2	27.123	24.000	23.61
22		X	x	Cyclone OF	3	34.791	27.300	30.28
23		X	x	Cyclone OF	4	6.831	6.300	5.947
24		X	x	Cyclone OF	5	2.765	3.000	2.407

Figure 54. 2D case solved. Please note that when changing from 1D to 2D, the 1D mass balance is frozen, i.e. it will not be changed. 2D data does not need to be complete: some streams mass balanced in 1D may miss some analyses and some components may be missing in 2D data.

48.11. Examples

See examples in folder HSC7\Flowsheet_MassBalancing\

- Example 1D Components
- Example 2D Minerals
- Example Copper Circuit

The relevant manual is “49 Sim Mass Balancing Examples.doc”. Please also check the HSC Forum (www.hsc-chemistry.com, Forum; or directly http://www.hsc-chemistry.com/forum_v3/) for updates and new examples.

48.12. Math

Definitions

N_{F1} = number of flows , 1D
N_{F2} = number of flows , 2D
N_U = number of units
N_{SRU} = number of size reducing units
N_{SF} = number of sub-flows
N_E = number of chemical elements
G = grade of chemical element
G^M = measured grade of chemical element
F = solids flowrate
F^M = measured solids flowrate
W = water flowrate
W^M = measured water flowrate
Pc = %solids= $F*100/(F+W)$
Pc^M = measured %solids
M = fraction m% = $F_{flow,subflow}*100/F_{flow}$
M^M = fraction m% measurements

$$e_{flow}^{unit} = \begin{cases} 1, & the \quad flow \quad enters \quad the \quad unit \\ -1, & the \quad flow \quad exits \quad from \quad the \quad unit \\ 0, & otherwise \end{cases}$$

48.12.1. 1D Mass Balance

In the 1D mass balance solution, solids and water flowrates are solved first. After that the 1D analyses are solved. The solids and water flowrates can be solved simultaneously or so that the solids flowrates are solved first and after that the water flowrates are solved.

1D flowrates

The solids flowrate solution first and the water flowrate solution after that

The equations for 1D solids flowrate solution are:

(1a) mass balance equations

$$\sum_{flow=1}^{N_{F1}} e_{flow}^{unit} * F_{flow,tot} = 0 \qquad unit = 1,..,N_U$$

(1b) analyses

$$\sum_{flow=1}^{N_{F1}} e_{flow}^{unit} * G_{flow,tot,chemical\_element}^{M} * F_{flow,tot} \approx 0 \qquad unit = 1,...,N_U$$

$$chemical\_element = 1,...,N_E$$

(1c) solids flowrate measurements

$$F_{flow,tot} \approx F_{flow,tot}^{M} \qquad flow = 1,...,N_{F1}$$

The equations for 1D water flowrate solution are:

(1d) mass balance equations

$$\sum_{flow=1}^{N_{F1}} e_{flow}^{unit} * W_{flow,tot} = 0 \qquad unit = 1,..,N_U$$

(1e) water flowrate measurements

$$W_{flow,tot} \approx W_{flow,tot}^{M} \qquad flow = 1,..,N_{F1}$$

(1f) % solids measurements

$$(Pc^{M}/100) * W_{flow,tot} \approx F_{flow,tot} - (Pc^{M}/100) * F_{flow,tot} \qquad flow = 1,..,N_{F1}$$

The mass balance equations (1a) and (1d) are the equality constraints for the solutions. The solution method used is the element-wise weighted total least squares [2]. The weights are standard deviations of the solids flowrate measurements F^M , the analyses G^M ,the water flowrate measurements, W^M and the %solids measurements Pc^M . The flowrates can be

solved without any constraints (LS), subject to non-negativity constraints (NNLS) [3] and subject to simple bounds

$$lb1 \le F \le ub1$$
$$lb2 \le W \le ub2$$

(MVLS) [4].

If there are no constraints, the minimal maximum norm solution can be calculated (LS, MinMax) [5] if only the solids are calculated.

The solids flowrates and the water flowrates are solved simultaneously

The equations are:

(1g) mass balance equations

$$\sum_{flow=1}^{N_{F1}} e_{flow}^{unit} * F_{flow,tot} = 0 \qquad unit = 1,..,N_U$$

$$\sum_{flow=1}^{N_{F1}} e_{flow}^{unit} * W_{flow,tot} = 0 \qquad unit = 1,..,N_U$$

(1h) solids and water flowrate measurements

$$F_{flow,tot} \approx F_{flow,tot}^{M} \qquad flow = 1,...,N_{F1}$$
$$W_{flow,tot} \approx W_{flow,tot}^{M} \qquad flow = 1,..,N_{F1}$$

(1i) %solids measurements

$$(1 - Pc^M/100) * F_{flow,tot} + (Pc^M/100) * W_{flow,tot} \approx 0 \qquad flow = 1,..,N_{F1}$$

The mass balance equations (1g) are equality constraints for the solution. The solution method used is the element-wise weighted total least squares. The weights are standard deviations of the solids flowrate measurements F^M , the analyses G^M ,the water flowrate measurements, W^M and the % solids measurements Pc^M .

As before, the flowrates can be solved be solved without any constraints (LS), subject to non-negativity constraints (NNLS) and subject to simple bounds (MVLS).

1D analyses

Let G and G^M be $N_{F1} \times N_E$ matrices. The operator vec stacks the columns of a matrix into a vector.

The equations for the analyses solution are:

(2a) the measurements

$$vec(G) \approx vec(G^M)$$

(2b) the mass balance equations for the analyses

$$vec(B * G) = 0$$

where the $N_U \times N_{F1}$ matrix B is defined

$$B_{unit,\,flow} = e_{unit}^{flow} * F_{flow,tot}$$

(2c) if the option minerals sum=100 is selected the following equations are included

$$\sum_{chemicalelement=1}^{N_E} G_{flow,tot,chemical\_element} = 100 \qquad flow = 1,\ldots,N_{F1}$$

Equations (2b) and (2c) are the equality constraints for the solution. The solution method used is weighted least squares (1). If equations (2c) are included in equations (2b), the matrix B is $(N_U - 1) \times N_{F1}$ to avoid linear dependency of equality constraints.

As before the analyses can be solved be solved without any constraints (LS), subject to non-negativity constraints (NNLS) and subject to simple bounds (MVLS). If there is no constraints minimal maximum norm solution can be calculated (LS, MinMax) [5].

48.12.2. 1.5 D Mass Balance

1.5D differs from the 1D solution in that the fraction m% are solved and that the fraction m% measurement are used in the solution of total flows. 1.5D differs from 2D in that the analyses are not given and that the number of flows is same as in 1D .

The total flows mass balance

Firstly, the total flows are solved. The equations are:

(2a) the mass balance equations

$$\sum_{flow=1}^{N_{F1}} e_{flow}^{unit} * F_{flow,tot} = 0 \qquad unit = 1,..,N_U$$

(2b) the fraction m% measurements

$$\sum_{flow=1}^{N_{F1}} e_{flow}^{unit} * M_{flow,subflow}^{M} * F_{flow,tot} \approx 0 \qquad unit = 1,..., N_U - N_{SRU} - 1$$

$$subflow = 1,.., N_{SF}$$

Units are indexed up to $N_U - N_{SRU} - 1$ to avoid linear dependency of equality constraints.

(2c) the flow measurements

$$F_{flow,tot} \approx F_{flow,tot}^{M} \qquad flow = 1,..., N_{F1}$$

If 1D analyses are given, the following equations are included:

(2d) the analyses

$$\sum_{flow=1}^{N_{F1}} e_{flow}^{unit} * G_{flow,tot,chemical\_element}^{M} * F_{flow,tot} \approx 0 \qquad unit = 1,..., N_U$$

$$chemical\_element = 1,..., N_E$$

The equations (2a) are equality constraints for the solution. The solution method used is the element-wise weighted total least squares. . The weights are standard deviations of the solids flowrate measurements F^M , the analyses G^M and fraction m% M^M .

As before, the flowrates can be solved without any constraints (LS), subject to non-negativity constraints(NNLS), and subject to simple bounds (MVLS). If there are no constraints, the minimal maximum norm solution can be calculated (LS, MinMax) [5].

The sub-flow mass balance

Then the %m values of sub-flows are solved. The equations are:

(2e) the fraction m% measurements

$$M_{flow,subflow} \approx M_{flow,subflow}^{M}$$

(2f) the mass balance equations

$$\sum_{flow=1}^{N_{F1}} e_{flow}^{unit} * M_{flow,subflow} * F_{flow,tot} = 0 \qquad unit = 1,..., N_U \quad unit \quad not \quad size \quad reducing$$

$$subflow = 1,.., N_{SF}$$

(2g) sum fraction m% is a hundred

$$\sum_{i=1}^{N_{SF}} M_{flow,subflow} = 100$$

Equations (2f) and (2g) are equality constraints. The solution method used is the element-wise total least squares and %m values can be solved without any constraints (LS), subject to non-negativity constraints (NNLS) and subject to simple bounds (MVLS).

If there are no constraints, the minimal maximum norm solution can be calculated (LS, MinMax) [5].

1D analyses

If 1D analyses are given, the balanced analyses are calculated as in 1D Analyses.

48.12.3. 2D MASS BALANCE

Before a 2D mass balance solution, 1D or 1.5D mass balance must be solved. The results $F_{flow,tot}$ of the 1D or 1.5D solution are used in 2D solution. In a 2D solution, the sub-flows are calculated first and after that the analyses are solved.

2D sub-flows

The equations for 2D sub-flows solution are:

(3a) mass balance equations for each unit that is not size reducing

$$\sum_{flow=1}^{N_{F2}} e_{flow}^{unit} * F_{flow,subflow} = 0 \qquad unit = n_1,...,n_{NU-1} \quad unit \quad not \quad size \quad reducing$$

$$subflow = 1,..,N_S$$

Above n_i is the index of ith unit that is not size reducing. Units are indexed up to $N_U - 1$ to avoid linear dependency of equality constraints.

(3b) sum of sub-flows is the total flow

$$\sum_{subflow=1}^{NS} F_{flow,subflow} = F_{flow,tot} \qquad flow = 1,...,N_{F2}$$

(3c) analyses for each unit that is not size reducing

$$\sum_{flow=1}^{N_{F2}} e_{flow}^{unit} * G_{flow,chemical\_element,sublow} * F_{flow,subflow} \approx 0$$

$$unit = n_1,...,n_{NU} \quad unit \quad not \quad size \quad reducing$$
$$chemical\_element = 1,...,N_E$$
$$subflow = 1,..,N_S$$

(3d) fraction %m measurements

$$F_{flow,subflow} \approx M^{M}_{flow,subflow} * F_{flow,tot} / 100$$
$$flow = 1,..., N_{F2}$$
$$subflow = 1,.., N_S$$

or alternatively

(3f) flow measurements

$$F_{flow,subflow} \approx F^{M}_{flow,subflow}$$
$$flow = 1,..., N_{F2}$$
$$subflow = 1,..., N_S$$

The solution method used is the element-wise weighted least squares. The equations can be solved without any constraints (LS), subject to non-negativity constraints (NNLS) and subject to simple bounds (MVLS).

If there are no constraints, the minimal maximum norm solution can be calculated (LS, MinMax) [5].

2D analyses

Let G and G^M be $N_{F2*NS} \times N_E$ matrices. The operator vec stacks the columns of a matrix into a vector.

The equations for the analyses solution are:

(3f)

$$vec(G) \approx vec(G^M)$$

(3e) the mass balance equations for the analyses

$$vec(B * G) = 0$$

where the $(N_S - 1) * (N_U - N_{SRU}) \times (N_{F2} * (N_S - 1))$ matrix B is defined

$$B = diag(B^{subflow}) \qquad sublow = 1,.., N_S - 1$$

Sub-flows are indexed up to $N_S - 1$ to avoid linear dependency of equality constraints.

where the operator $diag$ add matrices $B^{subflow}$ at the diagonal of the matrix B and $B^{sublow}_{unit,\,flow} = e^{unit}_{flow} * F_{flow,subflow}$

(3g) sum of sub-flows is the total flow

$$\sum_{subflow=1}^{NS} F_{flow,subflow} * G_{flow,chemical\_element,subflow} = F_{flow,tot} * G_{flow,tot,chemical\_element}$$

$$flow = 1,..., N_{F2}$$

$$chemical\_element = 1,..., N_E$$

(2f)
if the option minerals sum=100 is selected the following equations are included

$$\sum_{chemicalelement=1}^{N_E} G_{flow,chemical\_element,subflow} = 100 \qquad flow = 1,..., N_{F1}$$

$$subflow = 1,..., N_S$$

If equations (2f) are included B is $(N_S - 1) * (N_U - N_{SRU} - 1) \times (N_{F2} * (N_S - 1))$ to avoid linear dependencies.

The solution method used is the weighted least squares. The equations can be solved without any constraints (LS), subject to non-negativity constraints (NNLS) and subject to simple bounds (MVLS).

If there are no constraints, the minimal maximum norm solution can be calculated (LS, MinMax) [5].

48.13. References

[1] **Golub, van Loan**: Matrix Computations, Third edition 1996
[2] **Markovsky, Rastello, Premoli, Kuhush, van Huffel:** The element-wise weighted total least squares problem, Computational Statistic & Data Analysis 50 (2006) pp.181-209
[3] **Lawson, Hanson:** Solving Least Squares Problems, 1974
[4] **Haskell, Hanson:** An Algorithm for Linear Least Squares Problems with Equality and Nonnegativity Constraints, Mathematical Programming 21 (1981), pp.98-118
[5] **Barrodale, Phillips:** Algorithm 495, Solution of an Overdetermined System of Linear Equations in the Chebyshev Norm, ACM Transactions on Mathematical Software, Vol 1, No 3, September 1975, pp. 264-270.